TECHNICAL PAPER NO. 3

Revised 6 November 1947

IGLOO TESTS

Naval Proving Ground, Arco, Idaho

1945

Army-Navy Explosives Safety Board 2039 Tempo 2 Building
Washington, D. C.

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Publication of this paper was authorized by Colonel F. H. Miles, Jr., President of the Army-Navy Explosives Safety Board, 1 June 1946. It has been completely revised and rearranged, and much data not available at the time publication was first authorized have been added. This revision was made by Stanley W. Thompson, formerly a member of the staff of the Board. The conclusions are his and not necessarily those of the Army-Navy Explosives Safety Board and the Army and Navy Departments.

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Colonel, GSC,
President, Army-Navy Explosives Safety Board.

16 FEBRUARY 1948

ABSTRACT

1. The high-explosive igloo tests, conducted by the Army-Navy Explosives Safety Board at the Naval Proving Ground, Arco, Idaho, in 1945 indicated:

a. That the prescribed Army (400 feet) and Navy (500 feet) intermagazine safety distances for the storage of mass detonating types of ammunition containing 250,000 net pounds of high explosives in Army and Navy Standard concrete, arch-type, earth-covered (igloo) magazines may be safely reduced one-half without undue risk of propagation of explosions from magazine to magazine.

b. That the barricaded inhabited-building distances given in the American Table of Distances are not adequate for concrete, arch-type, earth-covered (igloo) magazines since the damage to buildings and injuries to personnel which may occur when the contents of an igloo mass detonates are too serious to be an acceptable risk.

c. That the temporary storage of 250,000 net pounds of high explosives in an earth-barricaded open storage site located halfway between existing Army concrete, arch-type, earth-covered (igloo) magazines is reasonably safe and permissible with respect to the nonpropagation of explosions from magazines to earth-barricaded open sites and vice versa.

d. That the intermagazine unbarricaded distance (800 feet) for 250,000 net pounds of high explosives affords reasonable protection against the propagation of explosions among open field stacks of mass detonating types of ammunition containing 250,000 net pounds of high explosives.

e. That the doors on the Navy concrete, arch-type, earth-covered magazines should be strengthened to provide better protection against explosions which may occur in adjacent magazines.

2. Data were obtained on—

a. The effects of earth cover and barricades in reducing blast pressures and the range of missiles.

b. The relative advantages of the Army and Navy Igloo designs, such as the better protection afforded by the Army-type door.

c. Blast pressures.

d. Meteorological effects.

e. Seismic action.

f. Missile distribution.

g. The appearance and action of the shock wave.

h. Crater size and shape.

i. Structural and glass damage to inhabited buildings of wood construction.

3. Moving pictures were taken of the explosions which are on file at the offices of the Army-Navy Explosives Safety Board. Of particular interest are the high speed pictures of the shock wave (taken at 1,450 frames per second) showing how the wave approaches and "flows over" the target igloo and then retreats in the suction phase before it is met by the missiles, dust cloud, and debris.

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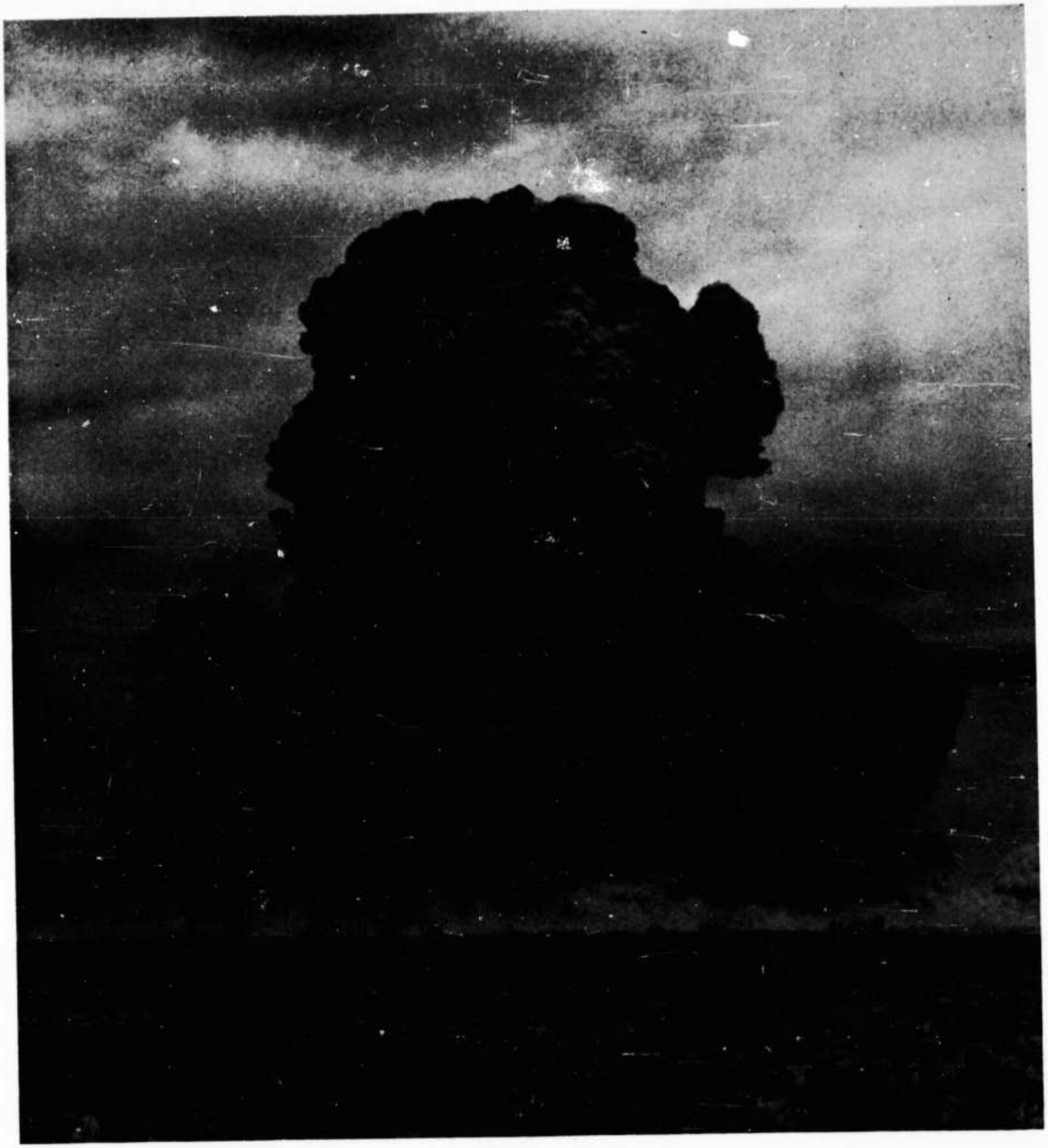

An H. E. igloo explosion

PART I. INTRODUCTION

A.—PURPOSE OF TESTS

1. At the cessation of hostilities of World War II there remained on hand in the continental United States and oversea Theaters of Operations tremendous stocks of Army and Navy ammunition. To provide for the orderly and economical disposition of these tremendous stocks of ammunition, it was essential that—

a. Temporary storage facilities be provided in the continental United States until the stocks required for peacetime use and the war reserve could be determined, and;

b. It be determined whether existing ammunition storage installations and facilities could be safely expanded without large expenditures for additional land, roads, and properties.

2. The program of tests conducted by the Army-Navy Explosives Safety Board at the Naval Proving Ground, Arco, Idaho, during the summer and fall of 1945 was designed to obtain these necessary data through the media of a limited number of full scale tests utilizing ammunition which was surplus to the needs of the War and Navy Departments.

3. To obtain the maximum benefit from the tests, the following government and scientific agencies interested in the control and effects of explosions were invited and participated:

a. Underwater Explosives Research Laboratory of the Woods Hole Oceanographic Institution.

b. OSRD (Office of Scientific Research and Development), Division 2 of the NDRC (National Defense Research Committee).

c. David Taylor Model Basin of the Navy Department.

d. U. S. Coast and Geodetic Survey, Commerce Department.

e. U. S. Weather Bureau of the Commerce Department.

f. U. S. Geological Survey of the Interior Department.

g. U. S. Bureau of Reclamation of the Interior Department.

4. Funds were also allotted for making a very limited check of the safety distances prescribed for inhabited buildings as set forth in the American Table of Distances.

B.—DESCRIPTION OF TEST SITE

1. The site chosen for the tests was the Naval Proving Ground, Arco, Idaho. This was the best of a number of sites which were investigated since it satisfied most of the requirements of isolation, availability of government facilities, availability of construction equipment and contractors competent to handle the construction, rail and highway facilities, power, water, and favorable weather conditions.

2. The Arco Naval Proving Ground is situated on a vast expanse of semiarid desert bordering the valley of the Snake River located to the north of the Snake River Plain and is 40 miles northwest of Blackfoot, Idaho, and 23 miles east of Arco, Idaho. The site lies southeast of the rugged Lemhi, Lost River, and Sawtooth Mountains from which the Little and Big Lost Rivers flow, disappearing in sinks on the desert. The position of the Igloo Tests (Igloo A) was 43°38′14″ north latitude, 112°53′25″ west longitude, at an elevation of approximately 4,855 feet.

3. The Snake River Plain was formed by the lava flows during the intense volcanic activity of the Pliocene period which continued in decreasing intensity until recent times. The flows at Craters of the Moon, 40 miles to the southwest, are estimated as having occurred only a few hundred years ago. At the test site 2 feet of fine silt topsoil cover a clay and gravel alluvium 15 feet in thickness which overlies the complex basaltic layers of lava formations. Numerous cones and lava outcrops protrude from the gently rolling desert. The

FIGURE 1. Test site.

log of the well at the gun emplacements of the NPG, table I, illustrates a typical geologic section.

4. The rainfall averages 12.5 inches a year with persistent southwest winds of 10 to 35 m. p. h. resulting in a low humidity and rapid drying conditions especially in the summer months. The sparse vegetation consists of sagebrush, bunch grass, small cacti, and similar desert growths.

TABLE I.—*Log of well at gun emplacements*

Depth below surface in feet:	Subsurface formation	Depth below surface in feet:	Subsurface formation
0	Top soil.	321	Hard gray lava.
2	Gravel.	341	Clay.
17	Clay.	349	Solid lava.
28	Lava with clay filled cracks.	352	Clay and cinders.
50	Lava with clay and sand mixed.	371	Clay.
59	Clay and sand.	381	Hard gray lava.
69	Solid lava.	391	Clay.
108	Lava and cinders.	414	Clay and gravel mixed.
134	Sand and clay.	425	Cinders.
139	Lava.	427	Clay and cinders.
145	Lava.	440	Solid lava.
159	Cinder and lava.	444	Blue lava crevice.
161	Lava.	449	Gray lava—water.
169	Cinders.	462	Blue lava crevice.
171	Cinder and clay mixture.	470	Honeycomb lava—traces of soapstone—water throughout.
181	Cinders.	522	Solid lava.
184	Solid lava.	562	Clay, lava and water.
211	Broken lava.	588	Solid lava.
221	Solid lava.	612	Red honeycomb lava.
231	Coarse lava.	665	Lava, cinders and water.
246	Brown lava.	677	Red lava, cinders.
265	Soft lava.	685	Red lava, cinders—well bottom.
281	Hard lava.		
291	Clay and lava mixed.		

C.—TEST PROGRAM AND PROCEDURE

1. Program

The program of H. E. Igloo tests conducted by the Army-Navy Explosives Safety Board at the Naval Proving Grounds, Arco, Idaho, in 1945 included six 250,000-pound tests and two 125,000-pound tests as follows:

Test No.	Date 1945 (time MWT)	Weight of explosive in lbs.	Type of explosive	Test unit	Target units
1	29 Aug. (0930)	250, 000	50/50 Amatol	Army Igloo A	Igloos B, C, D and wood frame barracks at 2,155 feet.
2	18 Oct. (1440)	125, 000	50/50 Amatol	Revetment 1	Igloos B, C, D and revetment 2.
3	19 Oct. (1215)	250, 000	Torpex	Navy Igloo C	Igloos B, D and Rev. 2 and wood frame barracks at 2,155 feet.
4	30 Oct. (0920)	250, 000	50/50 Amatol	Revetment 3	Igloos B, D and Rev. 2 and wood frame barracks at 2,155 feet.
5	30 Oct. (1250)	250, 000	Torpex	Army Igloo B	Igloo D, Rev. 2 and wood frame barracks at 2,155 feet.
6	30 Oct. (1500)	125, 000	50/50 Amatol	Revetment 2	None.
7	31 Oct. (1240)	250, 000	TNT, Tetryl 80/20 Amatol.	Stack 1	Stack 2 at 800 feet.
8	31 Oct. (1400)	250, 000	TNT	Stack 2	None.

2. Test layouts

The following units were constructed at the test site: two Army and two Navy standard concrete, arch-type, earth-covered (igloo) magazines approximately 26.5 x 81 feet in size; one standard two-story, wood frame, Navy-type barracks building approximately 36 x 96 feet in size; three temporary open storage sites (revetments) approximately 30 x 60 feet in size; and necessary auxiliary facilities such as camera stations, instrument and observation shelters, and dugouts. Figures 2, 3, 4, 5, 6, and 7 show the general layout of the test site, the test structures, and the open storage sites. The earth cover on the igloo magazines has approximately the contour of the head wall of the Navy magazine as shown in figure 4. The depth of the earth cover over the arch is approximately 2 feet.

3. Blast meter and gages

Air-blast pressures were measured by paper-blast meters, foil-blast meters, piston gages, ball crusher gages, David Taylor Model Basin (TMB) diaphragm gages and piezoelectric gages in Test 1. Only paper-blast meters were used in the other tests (2, 3, and 4) in which pressures were recorded. A plot of the locations of these meters and gages with respect to the centers of the explosions is included in the description of each test.

a. Paper-blast meters.—The Aberdeen Proving Ground Paper-Blast Meter (Ref. 1) consists of a series of circular paper diaphragms of different radii and the size of the smallest diaphragm broken in each blast meter by the blast is taken to be a measure of the intensity of the blast. Since the natural periods of vibration of these diaphragms are quite short compared to the duration of the blast, the size of the smallest diaphragm broken is believed to be determined by the peak pressure.

These meters, figures 8a and 8b, consist of two pieces of ¾-inch plywood in which ten holes of various diameters are cut. A piece of waxed paper is inserted between the pieces of plywood and the pieces are then bolted together. The meters were mounted on stakes approximately four feet above the ground, face on to the blast.

The hydrostatic pressures required to break the diaphragms are given in table II.

TABLE II.—*Hydrostatic pressures required to break paper meter diaphragms*

Diaphragm No.	Diameter of diaphragm in inches	Hydrostatic pressure (p. s. i.)	Diaphragm No.	Diameter of diaphragm in inches	Hydrostatic pressure (p. s. i.)
1	5. 65	0. 4	6	1. 00	2. 7
2	4. 00	. 6	7	. 75	3. 6
3	2. 83	. 8	8	. 50	5. 8
4	2. 00	1. 2	9	. 375	7. 7
5	1. 375	1. 8	10	. 25	12. 6

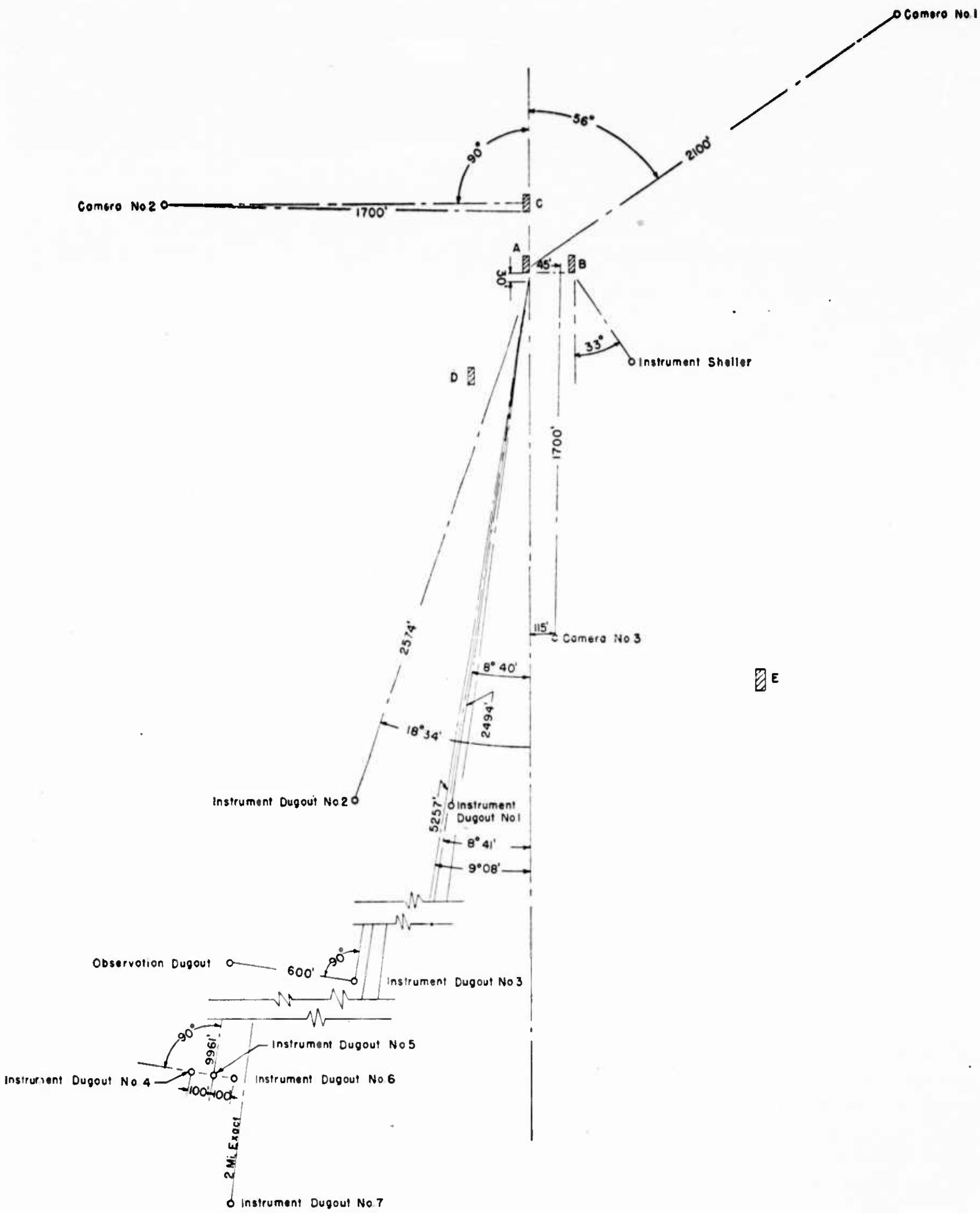

FIGURE 2. Location of primary and secondary elements.

Legend

Symbol	Element	Equipment or Agency
A	Primary igloo (Army Igloo).	Camera to record roof movement.
B	Army secondary magazine.	Strain and deflection gages.
C	Navy secondary magazine.	Do.
D	do	Do.
E	Barracks building	2,155′ from A.
Camera No. 1	35 m/m multiple lens camera, David Taylor Model Basin.	1,000 frames/sec.
Camera No. 2	16 m/m General Electric camera, David Taylor Model Basin.	1,430 frames/sec.
Camera No. 3	16 m/m General Electric camera, David Taylor Model Basin.	1,430 frames/sec.
Instrument shelter	Electronic instruments for measuring blast pressure.	David Taylor Model Basin.
Instrument dugout 1	Seismic instruments	Coast & Geodetic Survey.
	Strain gages	Bureau of Reclamation.
Instrument dugout 2	Seismic instruments	Coast & Geodetic Survey.
	Strain gages	Bureau of Reclamation.
	Accelerometers	David Taylor Model Basin.
Instrument dugout 3	Seismic instruments	Coast & Geodetic Survey.
	Accelerometers	David Taylor Model Basin.
Observation dugout	Firing point	
Instrument dugout 4	Instrument and camera control station.	
Instrument dugout 5	Generator station	
Instrument dugout 6	Seismic instruments	Coast & Geodetic Survey.
Instrument dugout 7	do	Do.

FIGURE 2. Location of primary and secondary elements—Continued.

b. NDRC foil blast meters (Ref. 2).

(1) A foil-blast meter is shown in figure 9a. It was constructed as shown in figure 9b. A sheet of aluminum foil 0.65 mils thick was inserted between the two pieces of masonite which form the orifice assembly and the two were then bolted together. The orifice plate assembly was taped around the edges to insure a seal and a small vent hole was drilled in the rear of each compartment to compensate for slow changes of pressure in the meter. These meters were mounted on wooden tripods five feet above the ground, side on to the blast. The hydrostatic pressures required to break the diaphragms are given in table III.

TABLE III.—*Hydrostatic pressures required to break NDRC foil meter diaphragms 0.65 mil aluminum foil*

Diameter of hole in inches	P. s. i. to break in parallel orientation (side-on to blast)	Diameter of hole in inches	P. s. i. to break in parallel orientation (side-on to blast)
1/2	12.9	1 1/8	6.18
9/16	12.5	1 7/16	5.09
5/8	11.5	1 7/8	3.96
11/16	10.5	2 1/2	2.97
13/16	8.42	3 1/2	2.10
15/16	7.35		

(2) Two additional box meters of similar design but of more rugged construction were used to record pressures near the center of the explosions. These meters, which were designed and constructed by Princeton University, had a range of 32 to 640 p. s. i. They were buried in the ground with the orifice plate flush with the surface of the ground.

c. British and Los Alamos Type Piston Gages (Ref. 2).

(1) Eight piston gages, designed and constructed by the Road Research Laboratory, in Great Britain, were provided for these tests. Nine

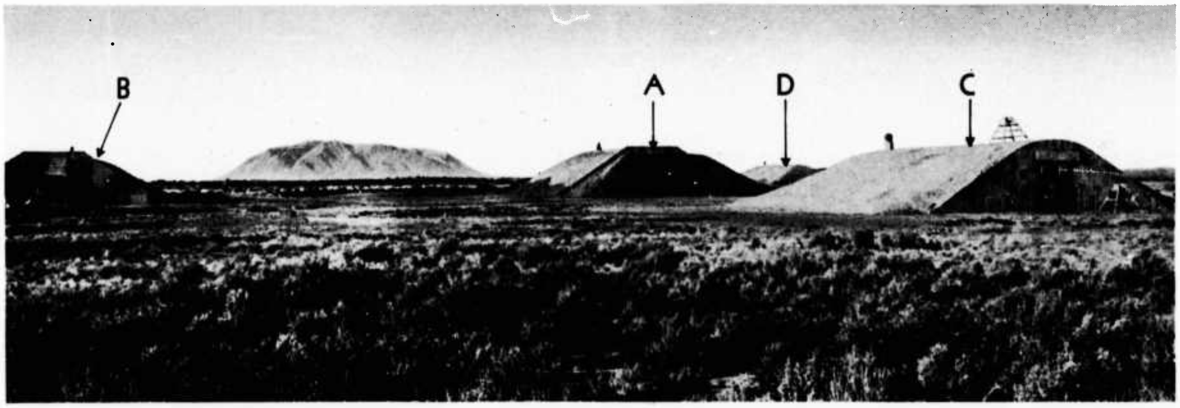

FIGURE 3. Igloos A, B, C, and D.

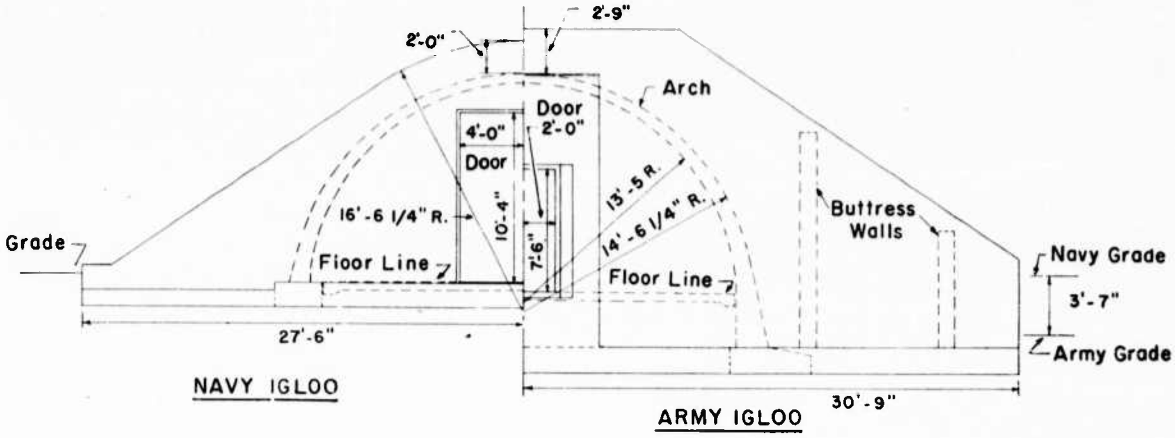

FIGURE 4. Composite drawing of cross-sectional dimensions of Army and Navy igloo type magazines.

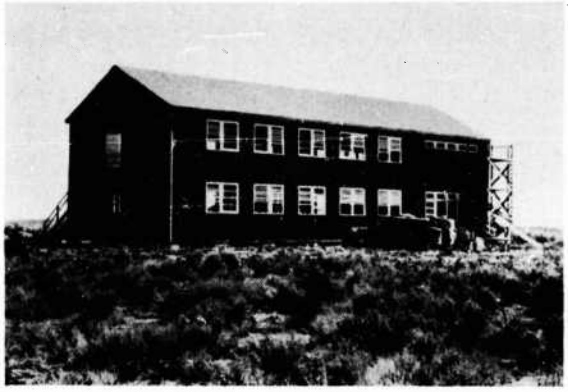

FIGURE 5. Navy-type barracks building.

FIGURE 6. Open storage site (revetment).

others, which were designed and constructed at Los Alamos, and which embodied improvements over the British gages, were also provided.

(2) The British-type piston gage consisted of a metal box, in one face of which were six holes of equal size. Closing these holes, from within the box, were six pistons held in place by springs whose compression could be adjusted. Motion of the pistons could be detected by the irreversible motion of other pistons bearing against them, but not coupled to them. Before the test, each pair of pistons was in contact; after the test, lack of contact between any pair of pistons indicated that they had moved. The spring forces were so adjusted that the pressure required to move each piston was different from all others. Thus, the blast pressure which had acted on the gage could be bracketed between those corresponding to two pistons, one of which moved while the other did not.

(3) The Los Alamos modification of these gages lay principally in the recording method, i. e., the means of detecting motion. Instead of a second piston, a piece of aluminum foil was tightly stretched opposite the inner end of each piston. This inner end was pointed, and a gap of about 5 mils was left between point and foil. Thus, a motion of 5 mils in any piston was detected by a dimple in the corresponding foil. This proved to be a more reliable indicating system than that in the original British gages.

d. UERL free-piston and spring-piston gages (Ref. 2).

(1) The free-piston gage consists of an unrestrained piston attached to a stylus which records the pressure change on the paper of a rotating drum. The motion of the piston as the blast wave acts on it is recorded by the stylus as a function of time, and the positive impulse of the blast and the peak pressure is computed from the record produced.

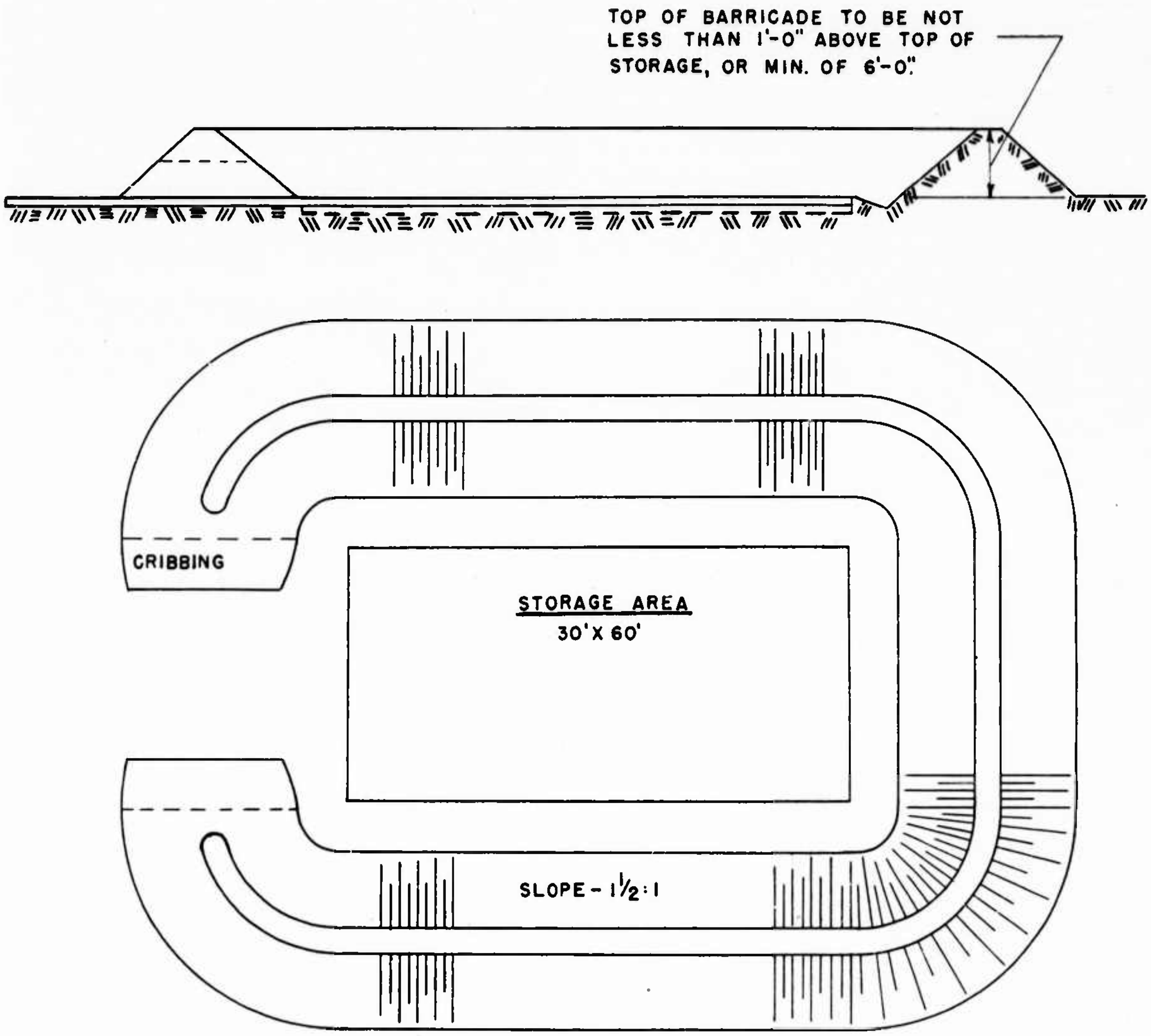

FIGURE 7. Typical revetment plan and profile.

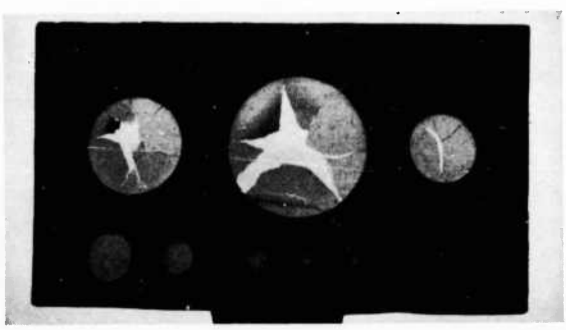

FIGURE 8a. Paper blast meter.

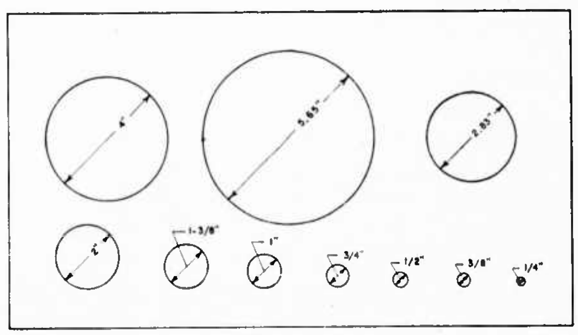

FIGURE 8b. Paper blast meter.

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(2) The spring-piston gage is similar to the free-piston gage, except that the motion of the piston is opposed by a spring. The movement of the piston is a measure of the peak pressure up to a maximum of 5.5 p. s. i.

e. NOL ball-crusher gage (Ref. 2).

(1) The ball-crusher gage was designed by the Naval Ordnance Laboratory to measure peak pressures in underwater shock waves, and was applied to the measurement of airblast peak pressures in these tests.

(2) The gage consists of a piston which bears on a spherical ball of soft copper. See figure 10. When the piston is depressed by the shock wave, the ball is deformed inelastically, and the diminution in diameter is nearly proportional to the peak pressure. For pressures below 100 p. s. i., the error may be quite large, and no measurable depression occurs at pressures less than about 70 p. s. i.

f. David Taylor Model Basin (TMB) diaphragm and piezoelectric gages (Ref. 3).—The electronic pressure measurements were taken by the Navy Department David Taylor Model Basin. Three different types of recording channels were used to obtain the pressure history of the explosion. One was the standard Taylor Model Basin channel for use with the David Taylor Model Basin Diaphragm-Blast Gage. The second type of channel was a modified version of the standard channel. Two of these modified channels were used. The third type consisted of five Rochelle-salt piezoelectric gages which served to record the time of arrival of the blast wave at selected positions.

(1) The standard channel consisted of—

(*a*) A diaphragm gage with a 500 ohm metalectric, spirally-wound strain element cemented to the inner face of the diaphragm.

(*b*) A ballast and battery box circuit.

(*c*) A combination preamplifier and natura frequency band-rejection filter.

(*d*) A Dumont Type 208 blue trace cathode-ray oscilloscope.

(2) The modified channel consisted of—

(*a*) A diaphragm gage with two 120 ohm metalectric, spirally-wound strain elements, one cemented to the outer and the other to the inner face of the diaphragm.

(*b*) A David Taylor Model Basin 1A strain indicator, which consists essentially of a circuit which has a Wheatstone bridge, two of whose arms are the two resistance elements of the pressure gage. The output of the bridge amplitude modulates a carrier wave of 2,000 cycles per second frequency. The modulated wave is then amplified and demodulated and the modulating signal is fed into a recording device.

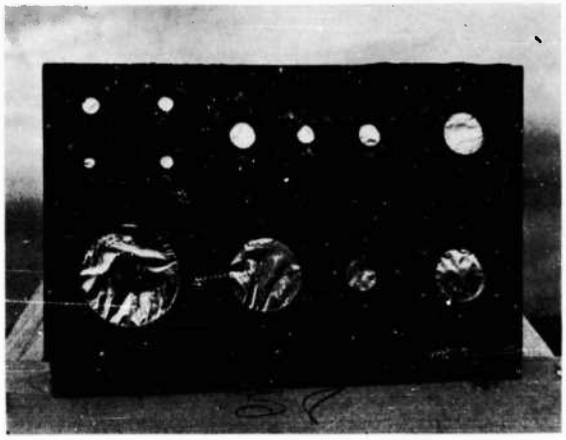


FIGURE 9a. NDRC foil blast meter.

(*c*) A General Electric string oscillograph on which the output of the strain indicator was recorded.

(3) The two channels were used because the standard channel has good high frequency response but poor low frequency response, while, on the other hand, the modified channel has good low frequency response but a poor high frequency response. It was hoped that a complete history of the blast pressures arising from the explosion might be obtained from a combination of the two records, the standard channel recording the initial peak pressure and the pressure occurring in the first 100 milliseconds and the modified channel recording any slowly varying pressure occurring later. At the high peak pressures expected, however, the pressure gage does not indicate the true peak pressure because a "Bernoulli flow" effect modified the pressure.

(4) The third type of channel employed was one that recorded the time of arrival of the blast-pressure wave at selected positions. By means of the distance-time curve and the Rankine-Hugoniot formula relating pressure and velocity of shock waves, it was hoped to obtain an accurate value of the peak pressure unmodified by any Bernoulli effects. The circuit consisted of five Rochelle-salt piezoelectric gages placed 40 feet apart. These gages were connected in parallel and placed across the input of a Dumont 208 cathode-ray oscilloscope. A 50,000-ohm resistor

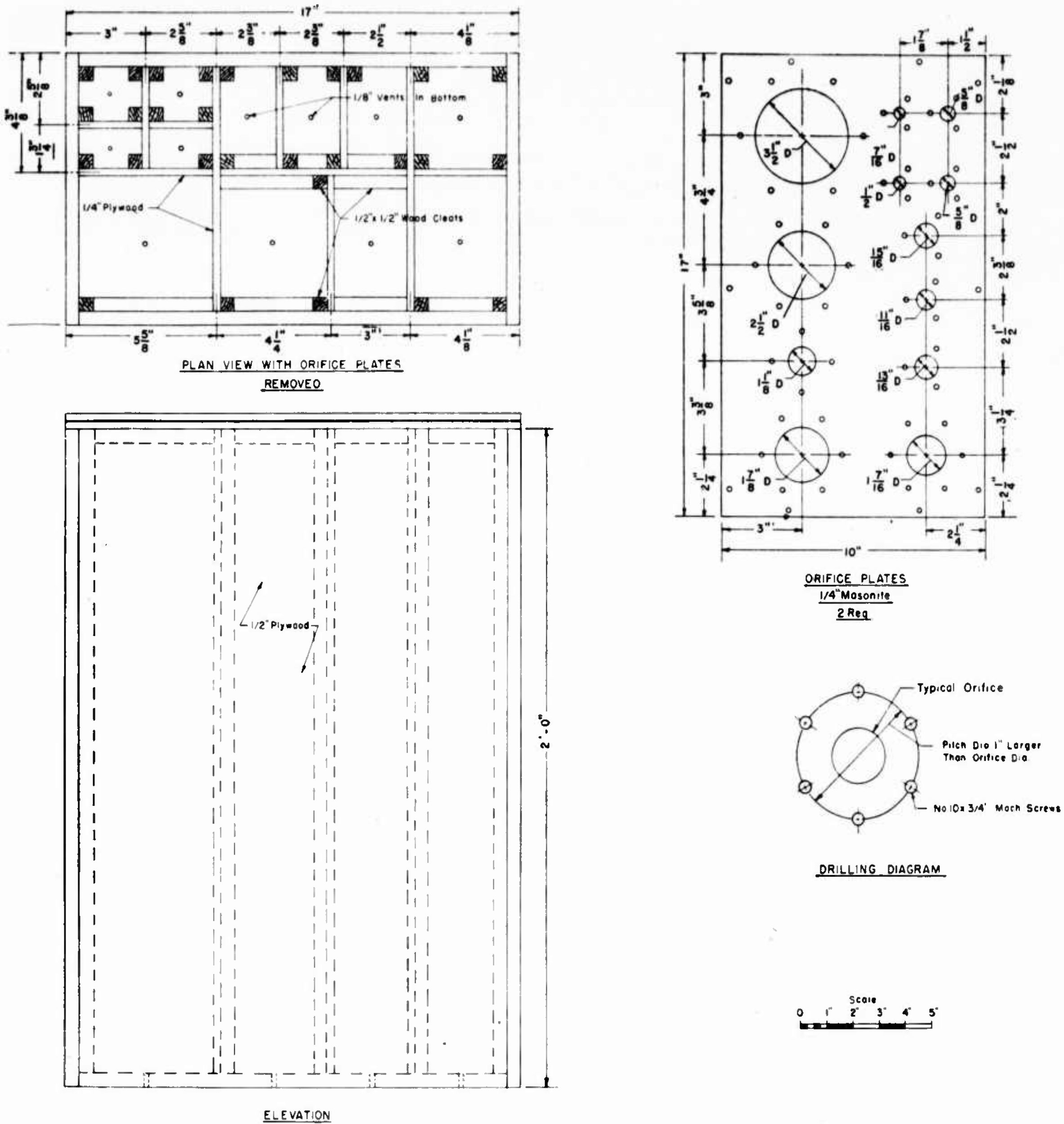


FIGURE 9b. NDRC foil blast meter.

was connected across the input terminals of the oscilloscope to provide an effective time constant of about one millisecond. This time constant insured that the signal from the first gage would disappear by the time the shock wave reached the second gage. The Rankine-Hugoniot formula is $(V/C)^2 = \frac{6}{7}P/P_0 + 1$,

where V is the velocity of the shock wave,

P is the excess pressure in the shock wave,
C is the velocity of sound,
P_0 is the atmospheric pressure.

(5) The outputs of the two modified channels using the Taylor Model Basin strain indicators were recorded on a General Electric string oscillograph with a film speed of about 15 inches per second. An electronic oscillator driving one of

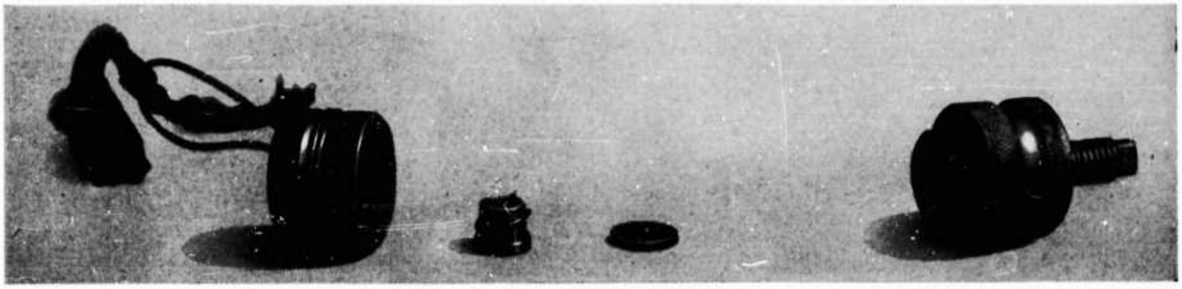


FIGURE 10. NOL ball crusher gage.

the strings at a frequency of 100 cycles per second provided a time base. The two Dumont 208 cathode-ray oscilloscopes were placed side by side and photographed by means of a General Radio Class 651 oscilloscope camera. A time base was provided by a 101.2 c. p. s. oscillator that discharged a spark from a spark coil through the film.

(6) The standard and modified Taylor Model Basin diaphragm gages were calibrated by determining the changes in resistance for known changes in static pressure.

(7) The piezoelectric gages were calibrated roughly by firing a one-pound charge of TNT and scaling the gage distances so as to obtain pressure of $\frac{1}{10}$ the magnitude expected from the actual explosion. An exact calibration was not required since it was only desired to know the time of arrival of the shock wave and not the pressure magnitudes. Each gage was mounted five feet above the ground with the gage positions 40 feet apart. A steel pipe filled with sand was located seven feet in front of each gage to serve as fragment protection.

4. Crater data

Crater measurements were taken in all tests, except Test 4, by means of field surveys.

5. Ground movement

Measurements of ground movement were made in Tests 1, 2, and 4 by means of field surveys.

6. Effect of blast on target igloos

The effects of the explosion on the target igloos was determined by observation and measured by means of a slide rule gage and a stop-point indicator (SPI) in Test 1, and by Carlson strain meters in Tests 2 and 4.

a. The gage (fig. 11) used to measure the arch deflection was a modified slide rule with the rule attached to a support from the floor and the slide attached to the arch. To minimize the overdrive a strong flat spring was inserted under the slides and to measure both outward and inward deflection the slide was divided into three parts. A disadvantage to this type of measurement was that it would measure a combination of arch deflection and relative floor-arch movement. This difficulty was overcome by using a second type instrument which measured the deflection of the arch between the haunch and springing line.

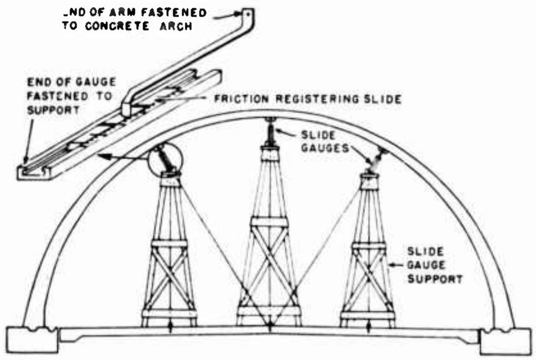


FIGURE 11. "Slide rule" gage.

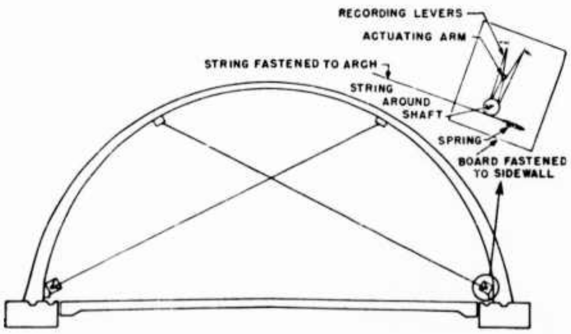


FIGURE 12. Stop point indicator.

b. This second instrument (fig. 12) consisted of an indicating arm, the movement of which was multiplied by a wheel lever. The wheel lever was actuated by the slack or tension in the string connected between the haunch and springing line of the arch. Two recording arms were actuated by the central or indicating arm and were held in place by friction. This instrument, called "stop-point indicator" (SPI), while carefully constructed, is believed to be subject to errors due to elasticity of the string and the looseness in the bearings.

c. The effect of the blast on target Igloo C in Test 2 and B in Test 4 was determined by observation and by measurements obtained from the Carlson strain meters installed by the Bureau of Reclamation (Ref. 4). The Carlson meter is a temperature-compensated elastic-wire-type instrument in which the strain sensitive element is enclosed in an expansible metal tube 10 inches long by ¾ inch in diameter. In installing the meters on the outside of the igloo, the earth backfill was first removed at the proper locations, next the meters were fastened in place by brackets secured by concrete expansion bolts, and then the backfill was replaced. The lead wires from the Carlson meters were carried in trenches to the instrument dugout about 800 feet away where a Heiland oscillograph recorded the resistance changes of the meters. After appropriate calibration, the resistance changes are converted into strain and stress. The natural frequency of the oscillograph galvanometers was 40 cycles per second, and the sensitivity in conjunction with the Carlson meters was about 30 millionths inch per inch of strain (or about 12 p. s. i. stress) per 0.02 inch deflection of the light spot. One of the galvanometers was also connected to a wire which was wrapped around a bomb to indicate the exact time of blast.

Diagrams showing the locations of the meters placed on Igloo C in Test 2 and on Igloo B in Test 4 are included in the description of these tests.

7. Barracks damage

Barracks damage was recorded in Tests 1, 3, and 4.

8. Missile data

Missile data were recorded in Test 1 only, in which a thorough analysis of distribution was made through a field survey of missile density and size.

9. Seismological data

Seismic recording instruments were installed by several organizations to measure the ground shocks resulting from these explosions. The U. S. Geologic Survey had instruments at locations as far away as 250 miles but most of the instruments were located in the immediate vicinity of the explosions. Due to power failures and other causes the U. S. Geologic Survey and the Bureau of Reclamation failed to obtain records, but very good records were obtained by the U. S. Coast and Geodetic Survey and the David Taylor Model Basin of the Navy Department.

10. Meteorological data

Meteorological observations were made by the Weather Bureau and volunteer observers in Test 1. The Weather Bureau established observation stations up to 200 miles, alerted all weather stations and the general public up to 800 miles to listen for the sound of the blast, and establish theodolite stations to observe the smoke cloud.

11. Test operation

Observation points for the tests were coordinated by short wave radio and field telephone, and the explosives were detonated from the observation dugout.

PART II. TESTS AND RESULTS

A.—H. E. IGLOO TEST NO. 1—29 AUGUST 1945

1. Purpose

a. To determine if the mass detonation of 250,000 net pounds of high explosives stored in an Army test Igloo A with a Navy door barricade will propagate to an Army Igloo B located parallel to and 185 feet from test Igloo A; to a Navy Igloo C located in line with the test Igloo A and 210 feet in front of it; or to a Navy Igloo D with door barricade located diagonally to the rear and left of test Igloo A at a distance of 500 feet.

b. To determine the severity of the damage done to the target igloos and their contents, and to a wooden barracks building E located diagonally to the rear and right of the test Igloo A at a distance of 2,155 feet.

c. To record data pertaining to air blast pressures, seismic action, meteorological effects, crater size, missile distribution and the appearance and action of the shock wave as revealed by high speed photography.

2. Layout

This test involved the explosion of 250,000 pounds of 50/50 Amatol in Army Igloo A with a Navy door barricade *vs.* target Igloos B, C, and D and a Navy-type wooden barracks building. Figure 13 shows the layout of the primary elements. The camera stations, instruments shelters and instrument and observation dugouts were located as shown in figure 2.

3. Igloo contents

a Igloos A and B were each loaded with four hundred and twenty-five 1,100-pound bombs, explosive charge 588 pounds of 50/50 Amatol (similar to Army 1,100-pound bomb MK–33). These bombs were stowed on wooden dunnage as shown in figures 14a and 14b.

b. Igloos C and D were each loaded with five hundred and forty-one 650-pound aircraft depth bombs (MK–49), explosive charge 462 pounds Torpex, stowed as shown in figures 15 and 16.

4. Priming

a. All bombs in Igloo A were primed by packing knotted primacord surrounded by composition C–2 into the nose fuse cavity of each bomb.

b. The method employed in connecting the bombs of each stack by running a primary lead of primacord "1" connecting the outside bombs in the stack, and secondary leads "2" and "3" connecting the remaining bombs to the primary lead is shown in figures 17a and 17b.

c. The primary lead from one stack was joined with the adjacent stack and the connections were made to the three electric Engineer Special Blasting caps in the center of the magazine as shown in figure 18. These caps were connected to the priming circuit in parallel, and the length and arrangement of the leads was such that all stacks fired simultaneously.

5. Description of test and summary of results

a. General.—The explosion of the 250,000 pounds of Amatol in Igloo A produced an initial flash and then streamers of smoke that shot out at angles above 30° from the horizontal forming a bush-like cloud that engulfed the flames within. This cloud merged with the dust near the ground and developed into a billowing black mass of smoke rising to a height of 2,380 feet in 2 minutes. (See figs. 19a and 19b.)

Observers at 1, 2, and 3 miles from Igloo A experienced a sudden puff of wind and ground shock accompanied by the sound of the explosion but felt no physical discomfort from the blast.

There was no propagation of the explosion from Igloo A to the target Igloos B, C, and D which suffered only minor damage. The barracks building suffered structural damage and extensive glass breakage, with the accompanying flying glass hazard.

b. Motion picture record.—Motion pictures were obtained from four different camera positions (fig. 2).

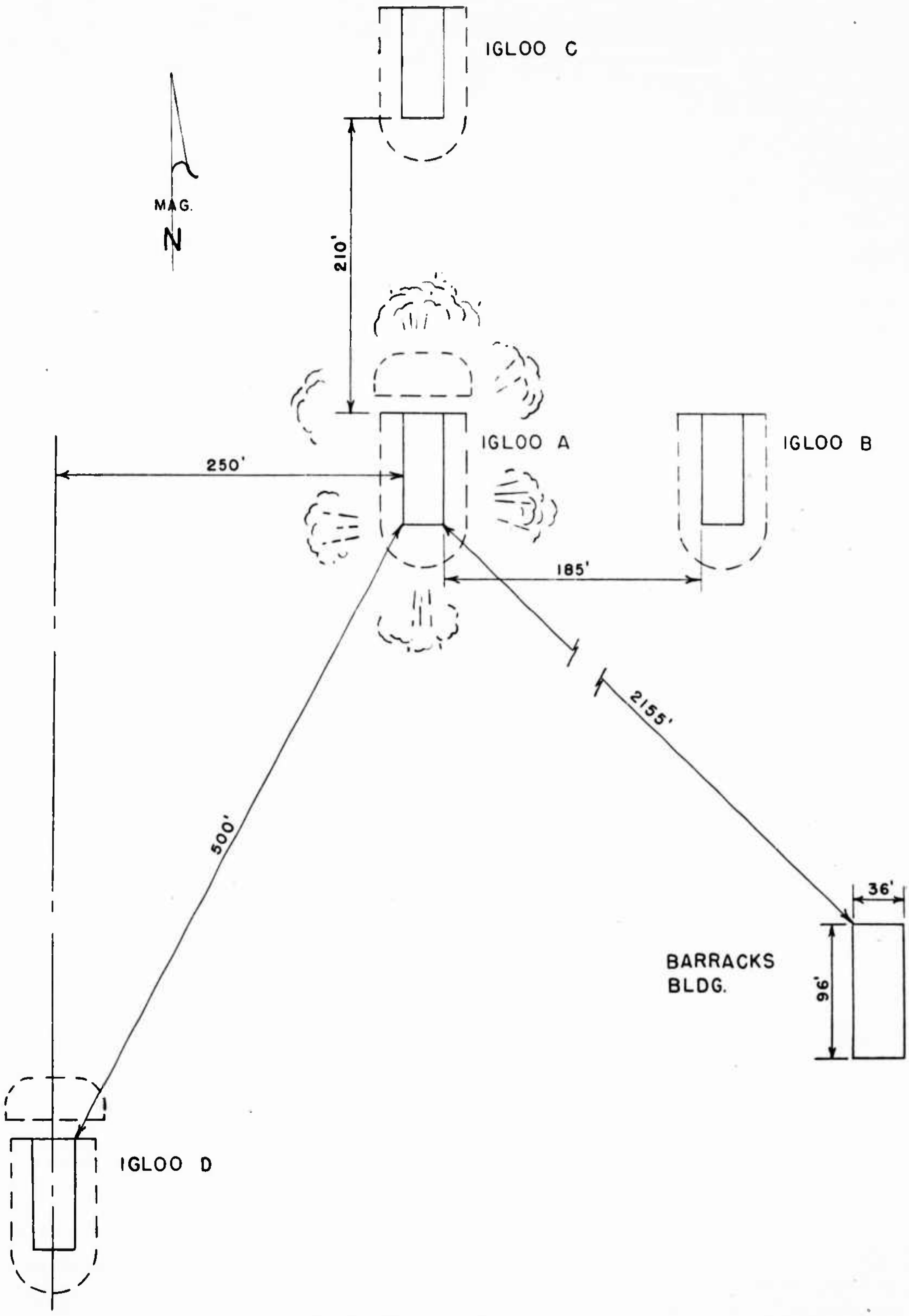


FIGURE 13. Field layout, Test 1.

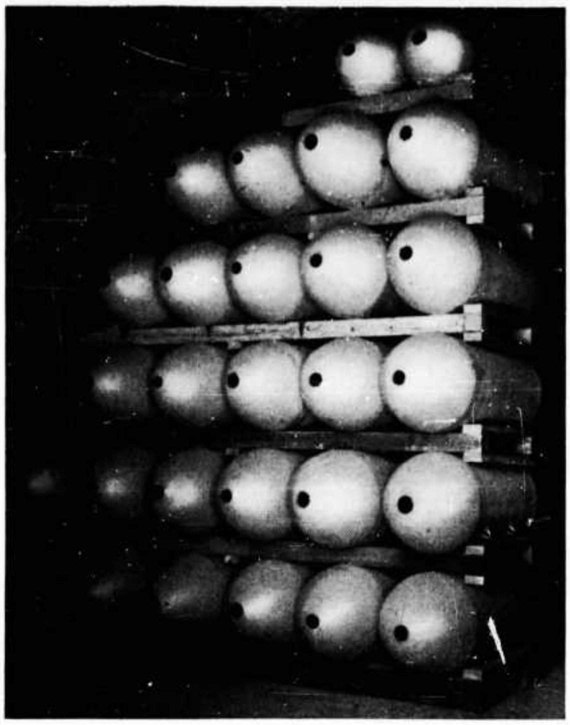


FIGURE 14a. Bomb stowage, Army Igloos A and B, Test 1.

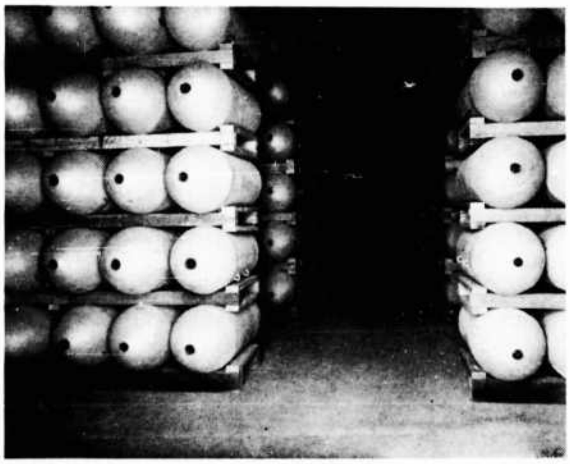


FIGURE 14b. Bomb stowage, Army Igloos A and B, Test 1.

(1) Pictures from the observation point showing the explosion of the 250,000 pounds of Amatol in Igloo A at normal film speed. (Camera 4.)

(2) Close-up of the explosion of Igloo A from the right front in high speed photography showing the sequence of events in the explosion of the Igloo. (Camera 1.)

(3) Close-up from the side of Igloo C showing the shock wave as it strikes Igloo C from the rear and passes over it. (Camera 2.)

(4) Close-up from the rear of Igloo B showing the shock wave as it strikes Igloo B from the side and passes over it. (Camera 3.) These films have been edited and combined into the complete film record of the explosive tests which are available at the offices of the Army-Navy Explosives Safety Board. Selected frames from the motion pictures are shown later in connection with the summary and discussion of results.

c. Air blast pressures.—The location of the various types of meters which were used in this test to measure air blast pressures are shown in figures 20a, 20b, and 20c. The records obtained from the meters are shown in tables IV, IVa, V, VI, VII, and VIII. It will be noted that the records obtained with the paper and foil meters were fairly consistent but that the records obtained from the other type gages varied widely. The records obtained from the electronic type gages

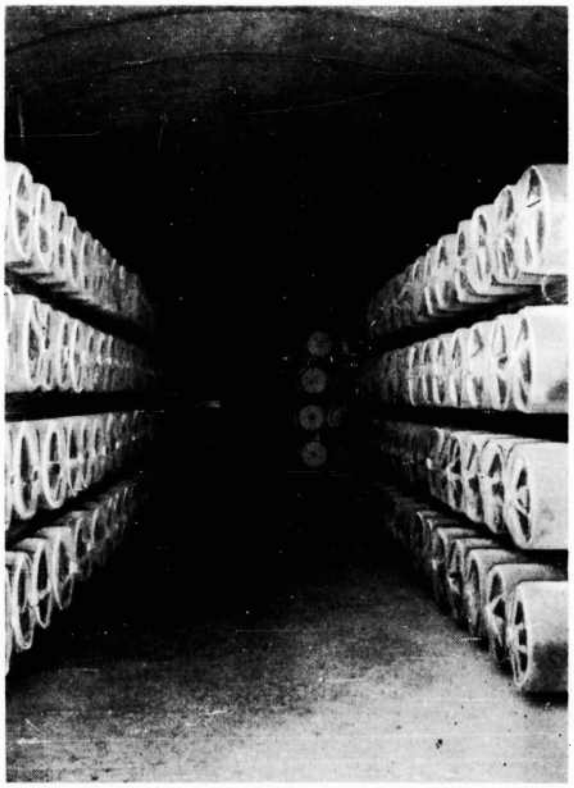


FIGURE 15. Bomb stowage, Navy Igloos C and D, Test 1.

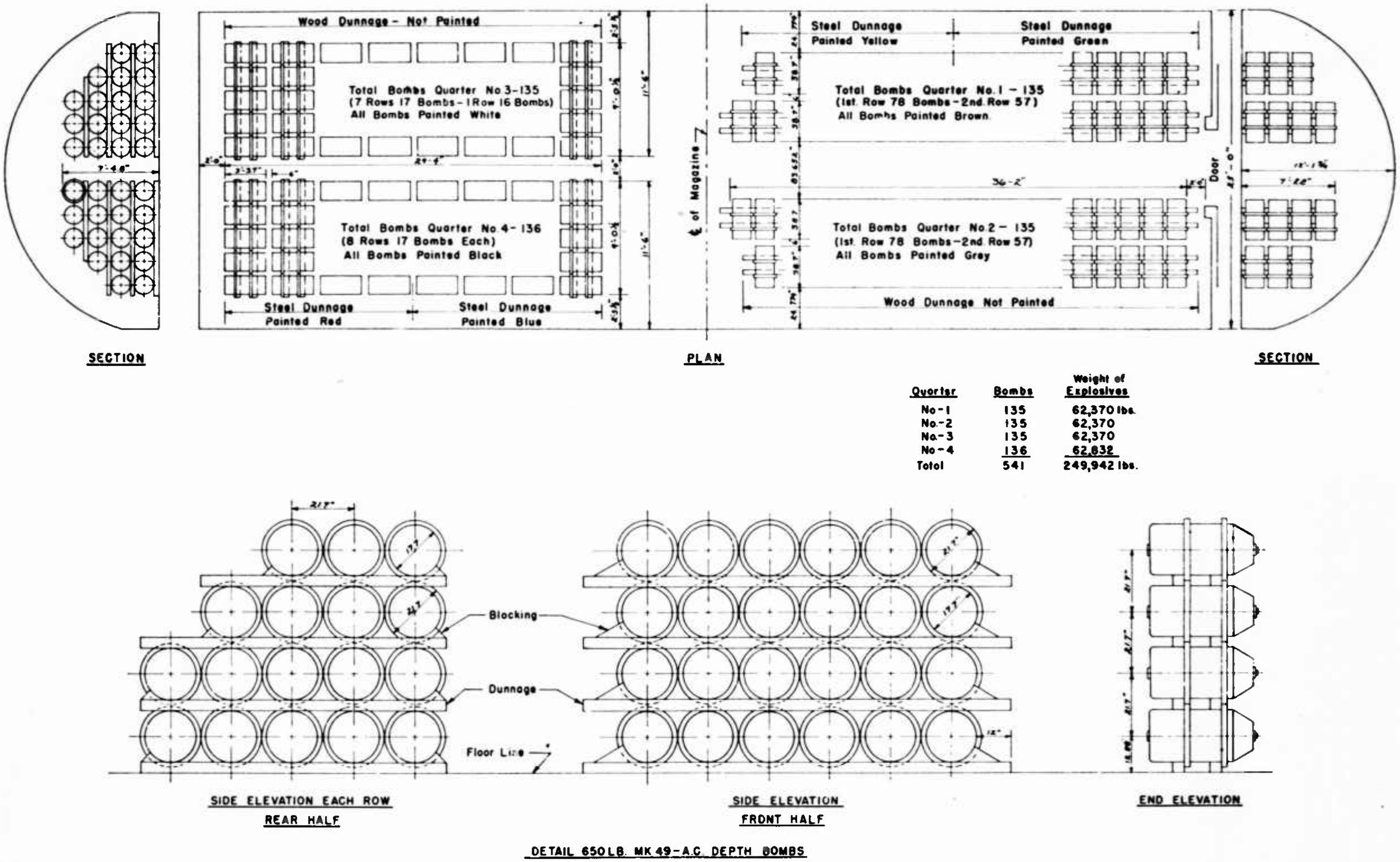


FIGURE 16. Igloo Test No. 1 bomb storage, Navy Igloos C and D.

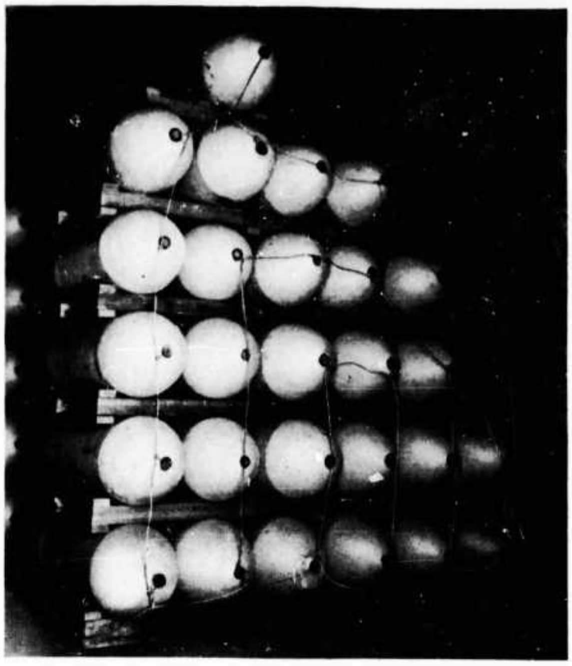


FIGURE 17a. Priming connections for each stack, Igloo A, Test 1.

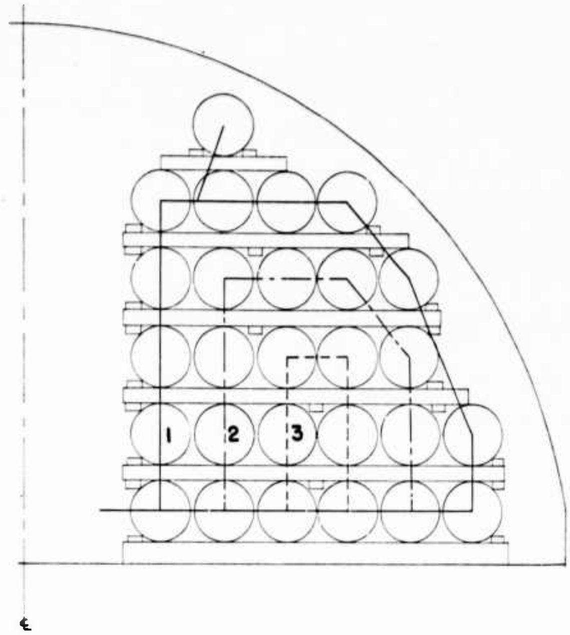


FIGURE 17b. Priming connections for each stack, Igloo A, Test 1.

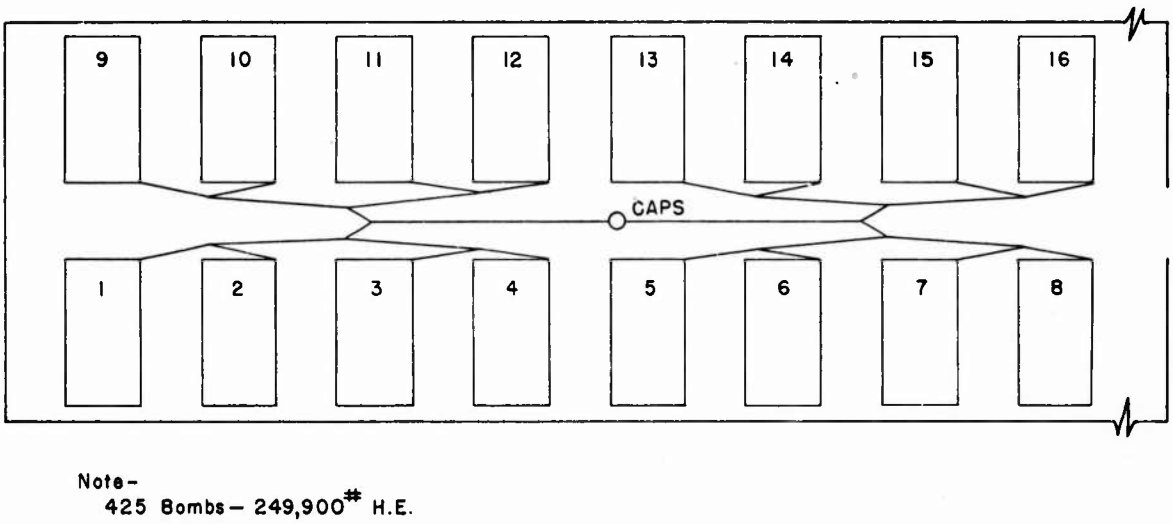


FIGURE 18. Priming plan for connecting stacks, Igloo A, Test 1.

were incomplete, as only the two strain indicator channels yielded results. This was due to the fact that the pressures were much lower than originally estimated and as a result, the amplifier gains were set too low and no signal could be detected.

d. Crater data.—The explosion of the contents of Igloo A produced a crater which was roughly oval in shape, having a long diameter of 200 feet along the longitudinal axis of the igloo, a short diameter of 150 feet, an apparent depth of 8 feet, and an actual depth of 13 feet (see fig. 21). A solid layer of lava was located at a depth of 17 feet which may have had some effect on the depth. Inside the ring of earth thrown out by the explosion a shoulder measuring from two to several feet in width was formed which was not at the original

FIGURE 19a. Explosion of Igloo A, Test 1, 1st stage.

FIGURE 19b. Explosion of Igloo A, Test 1, 2d stage.

TABLE IV.—*Test No. 1—29 August 1945—Air blast pressures paper meters on north and west lines*

[Fig. 20a]

Distance (ft.)*	North line (off front) (p. s. i.)	West line (off side) (p. s. i.)	Remarks	
			North line	West line
462	5. 8	7. 7	Blown over	Blown over.
488	3. 6	7. 7	do	Do.
517	3. 6	5. 8	do	Do.
548	3. 6	7. 7	do	Do.
582	3. 6	7. 7	do	Do.
615	3. 6	7. 7	do	Do.
650	2. 7	5. 8	do	Do.
691	3. 6	5. 8		Do.
731	2. 7	3. 6		Do.
775	2. 7	3. 6		Do.
820	2. 7	3. 6		Do.
868	2. 7	2. 7		
921	2. 7	2. 7		
975	2. 7	2. 7		
1,030	1. 8	2. 7		
1,100	1. 2	2. 7		
1,160	1. 2	1. 8		
1,230	1. 2	1. 8		
1,300	. 8	1. 8		
1,370	. 8	1. 8		
1,460	. 8	1. 8		
1,550	. 8	1. 2		
1,640	. 8	1. 2		
1,740	. 8	1. 2		
1,840	. 8	. 8		
1,940	. 6	. 8		
2,060	. 6	. 8		
2,180	. 6	. 6		
2,310	. 6	. 6		
2,450	. 4	. 6		
2,600	. 4	. 6		
2,740	0	. 6		
2,900	0	. 4		
3,080	0	0		
3,270	0	. 4		
3,460	0	. 4		
3,660	0	. 4		
3,880	0	. 4		
4,120	0	0		
4,350	0	0		

*This distance, for the West line, was measured from the corner formed by the front and west side of Igloo A, and for the North line from the center of the door of Igloo A. (See fig. 20a.)

ground level as shown by the crater plan and profile in figure 22.

e. Ground movement.—Permanent horizontal and vertical displacement of the ground caused by the explosion of Igloo A is given in figure 23. The vertical (upward) ground movement was consistent except to the north (front) where it was about 1/10 of that recorded in the other directions. The horizontal ground movement was also fairly consistent except to the north where no movement was recorded. The head wall of Igloo C moved north (away from the explosion) ½″ and west 1″

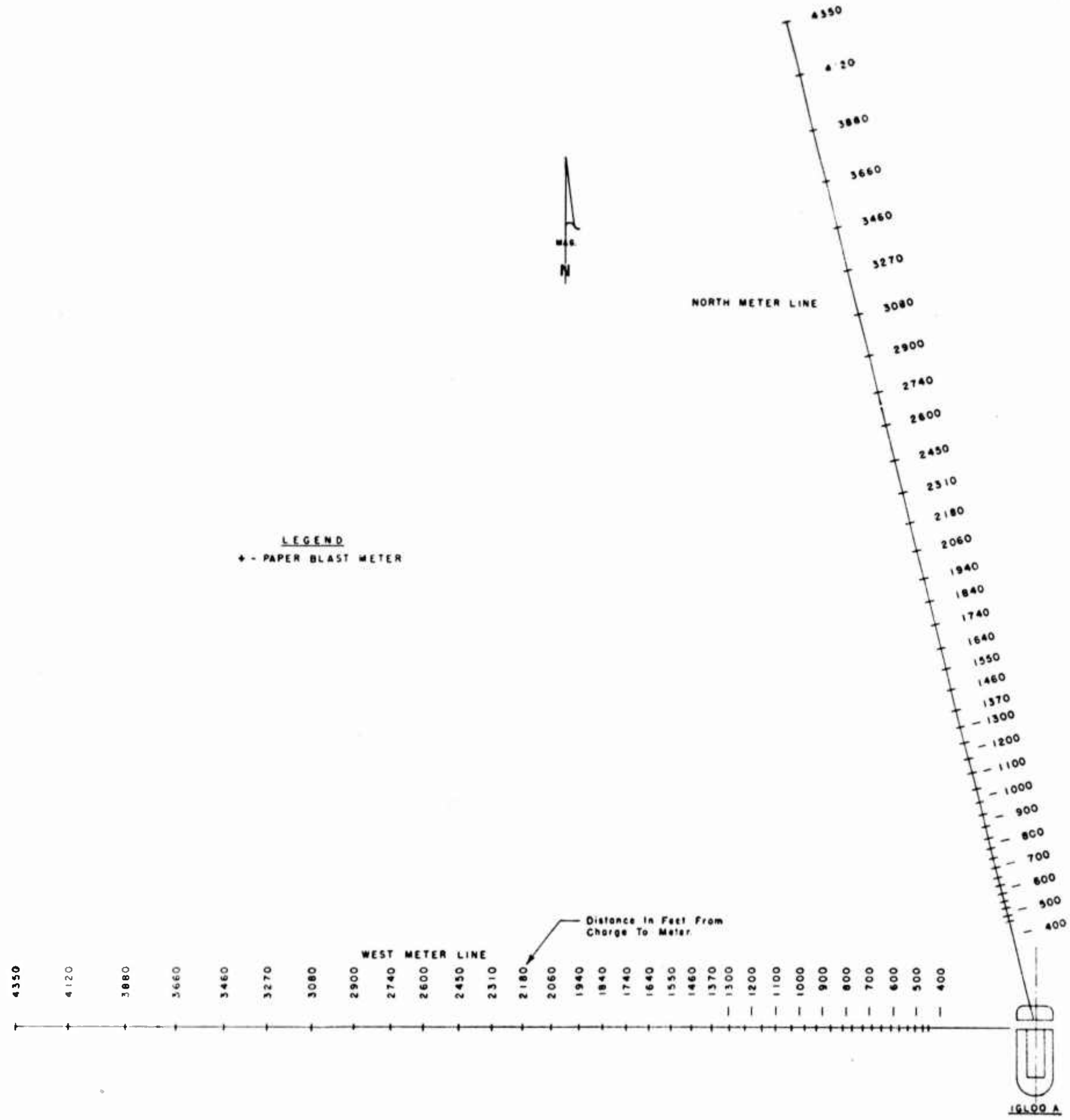


FIGURE 20a. Blast meter layout (paper meters north and west lines), Test 1.

with no recorded vertical movement; the head wall of Igloo B moved ½″ south (explosion was to the west) and there was no movement of Igloo D.

f. Effect of blast on target igloos.

(1) The igloo damage was minor and confined to the following:

(*a*) Slight arch cracking.

(*b*) Door damage in the Navy magazines.

(*c*) Ventilators blown off.

(2) Army-type Igloo B developed a crack across the center of the arch, which was a continuation of a crack previously noted and a new crack was formed along the center of the floor. The door was jammed, the earth cover slumped approximately two feet, and part of the ventilator was blown off (see fig. 24). In Navy-type Igloo C the door was blown in, the ventilator blown off, and one bomb was knocked off the stack and

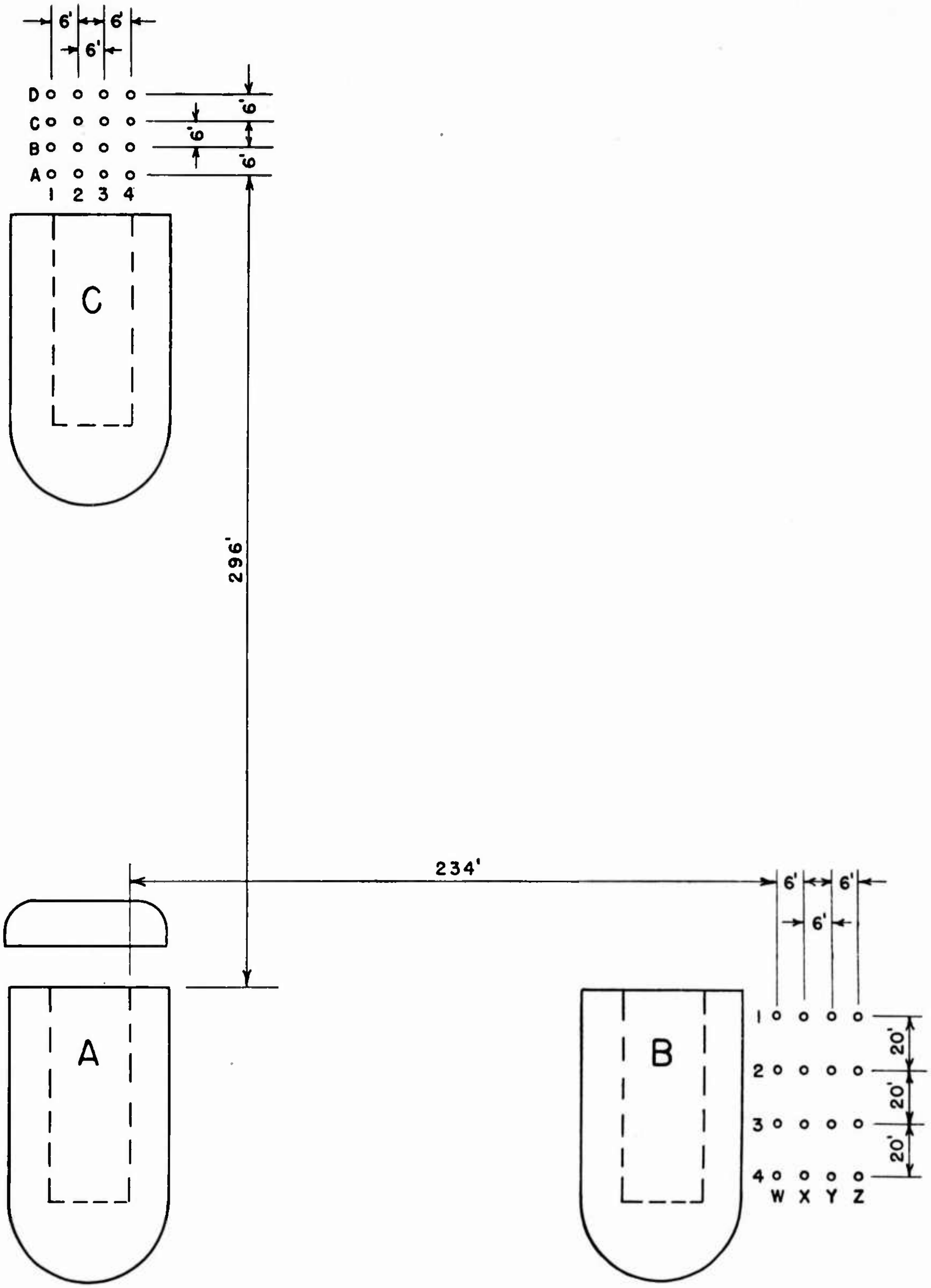


FIGURE 20b. Blast meter layout (paper meters at target igloos), Test 1.

TABLE IV-A.—*Test No. 1—29 August 1945—Air blast pressures paper meters at target igloo*

[Fig. 20b]

Distance from side of Igloo A, in feet	Meter No.	Pressure range in p. s. i.	Remarks
234	W–1	12. 6	Blown apart.
234	W–2	7. 7	Blown down.
234	W–3	7. 7	Do.
234	W–4	7. 7	Blown apart.
240	X–1	12. 6	Do.
240	X–2	7. 7	Blown down.
240	X–3	7. 7	Blown apart.
240	X–4	7. 7	Do.
246	Y–1	12. 6	Do.
246	Y–2	7. 7	Do.
246	Y–3	7. 7	Blown down.
246	Y–4	12. 6	Blown apart.
252	Z–1	12. 6	Do.
252	Z–2	12. 6	Do.
252	Z–3	12. 6	Do.
252	Z–4	7. 7	Do.

Distance from front of Igloo A, in feet	Meter No.	Pressure range in p. s. i.	Remarks
296	A–1	7. 7	Blown down.
296	A–2	1. 2	Do.
296	A–3	1. 8	Do.
296	A–4	2. 7	Do.
302	B–1	3. 6	Do.
302	B–2	2. 7	Do.
302	B–3	2. 7	Do.
302	B–4	3. 6	Do.
308	C–1	5. 8	Do.
308	C–2	3. 6	Do.
308	C–3	3. 6	Do.
308	C–4	3. 6	Do.
314	D–1	3. 6	Do.
314	D–2	3. 6	Do.
314	D–3	3. 6	Do.
314	D–4	3. 6	Do.

TABLE V.—*Test No. 1—29 August 1945—Air blast pressures, NDRC foil blast meters on west line*

[Fig. 20c]

Distance from center of Igloo A, in feet	West line (except as noted) (p. s. i.)	Note
270	11. 5	45′ east of Igloo B.
315	10. 5	15′ west of Igloo C.
315	7. 35	On top of Igloo C.
354	5. 09	15′ north of Igloo C.
450	10. 5	
475	8. 42	
500	7. 35	

TABLE V.—*Test No. 1—29 August 1945—Air blast pressures, NDRC foil blast meters on west line*—Continued

[Fig. 20c]

Distance from center of Igloo A, in feet	West line (except as noted) (p. s. i.)	Note
510	7. 35	In face of barricade Igloo D.
538	7. 35	Between barricade and Igloo D.
540	6. 18	
580	7. 35	
620	3. 96	
640	3. 96	
670	3. 96	
720	2. 97	
770	2. 97	
820	2. 97	
870	2. 97	
920	2. 97	
970	2. 97	
1,020	None	
1,070	2. 10	
1,120	3. 96	
1,170	2. 97	
1,220	None	
1,270	2. 10	

TABLE VI.—*Test No. 1—29 August 1945—Air blast pressures, British-type piston gages (Ref. 2)*

[Fig. 20c]

[The *range* of a gage lies between the pressure that will not move any of the pistons and the pressure that will move all the pistons. The *pressure limits* indicated by a gage are the highest pressure that will not move any of the pistons that did not move and the lowest pressure that will move all of the pistons that did move]

Distance from center of Igloo A (ft.)	Range of gage in p. s. i.	Observed pressure limits in p. s. i.
200	39. 5 – 69. 1	0 –39. 5
200	79 –127	0 –79
200	19. 7 – 39. 7	28. 9 –36. 6
200	19. 9 – 29. 9	29. 9 – 0
280	24. 6 – 61. 2	24. 6 –32. 3
280	17. 5 – 31. 0	17. 5 –19. 7
360	25. 9 – 60. 8	0 –25. 9
360	19. 7 – 30. 0	0 –19. 7
360	17. 9 – 31. 4	0 –17. 9
700	4. 05– 15. 35	0 – 4. 05
700	1. 05 11. 85	1. 05– 2. 2
800	6. 9 – 10. 25	0 – 6. 9
800	. 9 – 5. 07	1. 53– 1. 75
800	4. 0 – 6. 55	0 – 4. 0
1,300	. 83– 3. 35	0 – . 83
1,300	4. 25– 6. 4	0 – 4. 25
1,750	1. 0 – 3. 5	1. 0 – 1. 5

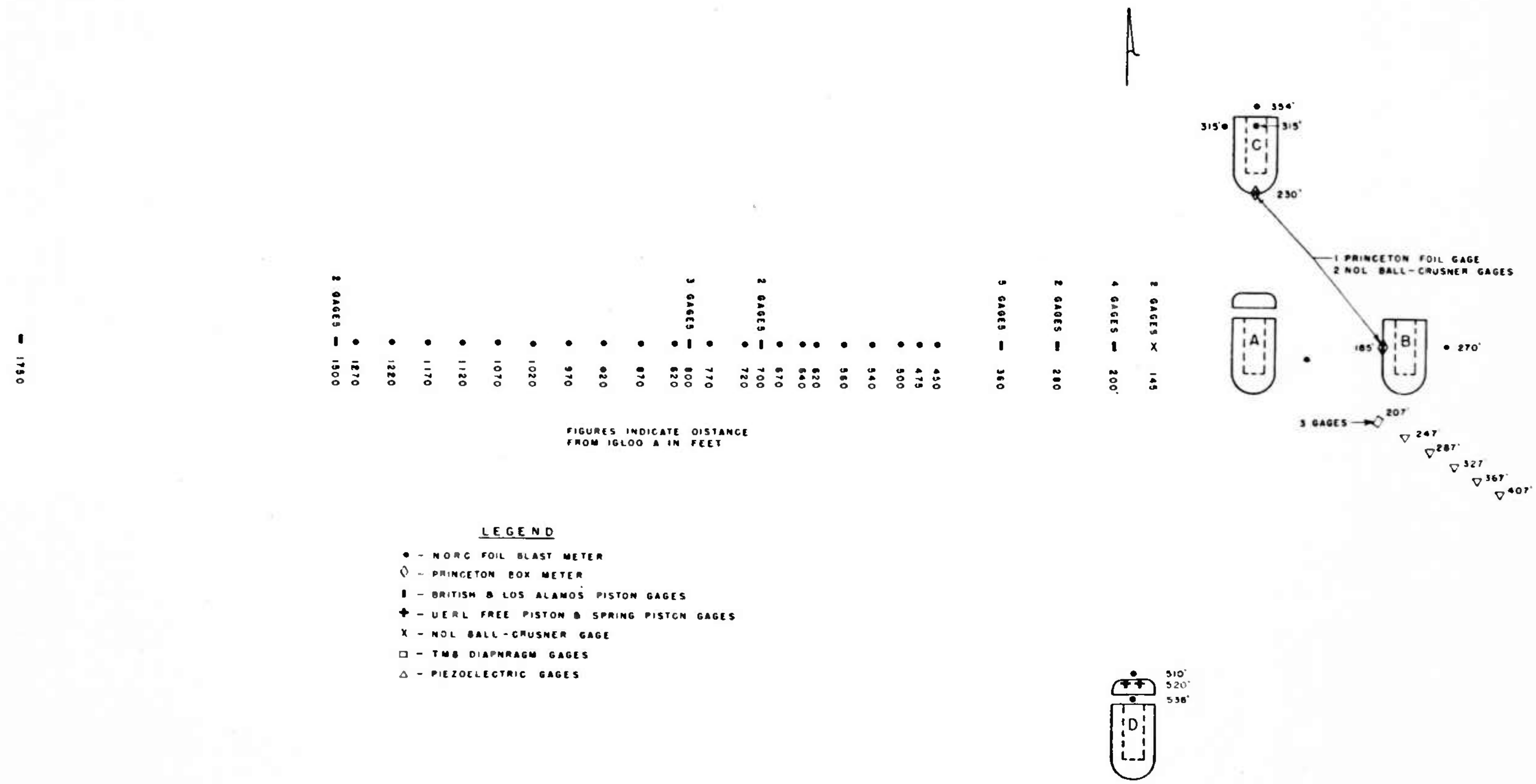


FIGURE 20c. Blast meter layout (except paper meters), Test 1.

TABLE VII.—*Test No. 1—29 August 1945—Air blast pressures various gages*

[Fig. 20c]

Gage location and type	Distance from center of Igloo A (ft.)	Indicated pressure in p. s. i.
Ball-crusher gages		
Off west side of Igloo A	145	96
Off west side of Igloo A	145	122
In earth cover on west side of Igloo B	185	79

Gages at 200 feet off the side of Igloo A, at 230 feet in the back of Igloo C, and one of the gages in the side of Igloo B gave no readings, indicating pressures at these points of less than 70 p. s. i.

Princeton box gages

These gages have a maximum range of 32 to 640 p. s. i.

In earth cover to the rear of Igloo C.	230	Less than 32
In the earth cover to the west side of Igloo B.	185	43 to 64.

Spring-piston gage

This gage cannot respond to a pressure greater than 5.5 p. s. i.

In the earth barricade of Igloo D	520	Greater than 5.5.

Free-piston gage

A motor failure caused the reading to be very uncertain.

		Positive impulse (lb msec in.²)
In the earth barricade of Igloo D	520	Greater than 210.

TABLE VIII.—*Test No. 1—29 August 1945—Air blast pressures electronic type gages*

[Fig. 20c]

	Gage location distance from center of Igloo A in feet	Maximum pressure p. s. i.	Maximum extrapolated pressure p. s. i.	Duration of positive pressure milliseconds
	207	14. 1	15. 3	
	207	9. 4	11. 7	39
Average		11. 8	13. 3	

Of the three types of channels used, only the two strain indicator channels yielded records.

another was tilted probably due to being struck by the door as it was blown inward (see fig. 25). No other bombs in any of the igloos were displaced. In Navy-type Igloo D the door was blown in (see fig. 26).

(3) "Slide-rule" and "stop-point indicator" deflection and strain gages (figs. 11 and 12) were installed in Igloos B, C, and D to measure the arch-floor movements. Permanent floor and arch movements were obtained by field surveys. Igloo B at 185 feet was stressed most severely and gave the greatest deflection readings. The arch deflected inward approximately 0.02 inches and spread outward as much as 0.04 inches. The maximum temporary relative movement of the floor and arch was 2.46 inches and the maximum permanent set was 0.17 inches. The arches of Igloos C and D showed almost no deflection. The maximum temporary relative floor-arch movements were 1.14 inches for Igloo C and 0.39 inches for Igloo D. The maximum permanent sets were 0.26 inches and 0.16 inches respectively. The recorded strains are shown diagramatically in figs. 27a, 27b, and 27c.

g. Damage to barracks and glass breakage.

(1) The barracks suffered considerable structural damage on the faces toward the explosion. Studding was broken, sheathing torn loose, window frames blown in or out, and the majority of the window panes were broken and thrown with sufficient force to cover the entire floor area with small fragments, with some pieces found imbedded in pillars and in the opposite wall. Both the north and south end first floor top plates were broken and the south wall, the wall away from the explosion, was pushed out approximately three inches.

(2) The building was in no danger of collapsing but it is doubtful if any occupant of the building would have escaped serious injury from flying glass, and several thousand dollars of damage was caused. Figure 28 shows a diagram of the damage and a key to the camera positions for the pictures illustrating the damage shown in figures 29 to 53.

h. Missiles and fragmentation.

(1) A careful search was made of the area surrounding Igloo A following the explosion and all observed missiles were recorded. An area of 2¼ square miles was covered and a total of 13,000 missiles were found. The pattern of the extreme range missiles was roughly symmetrical with the greatest distances along the igloo axis and along a line perpendicular to the axis and passing through

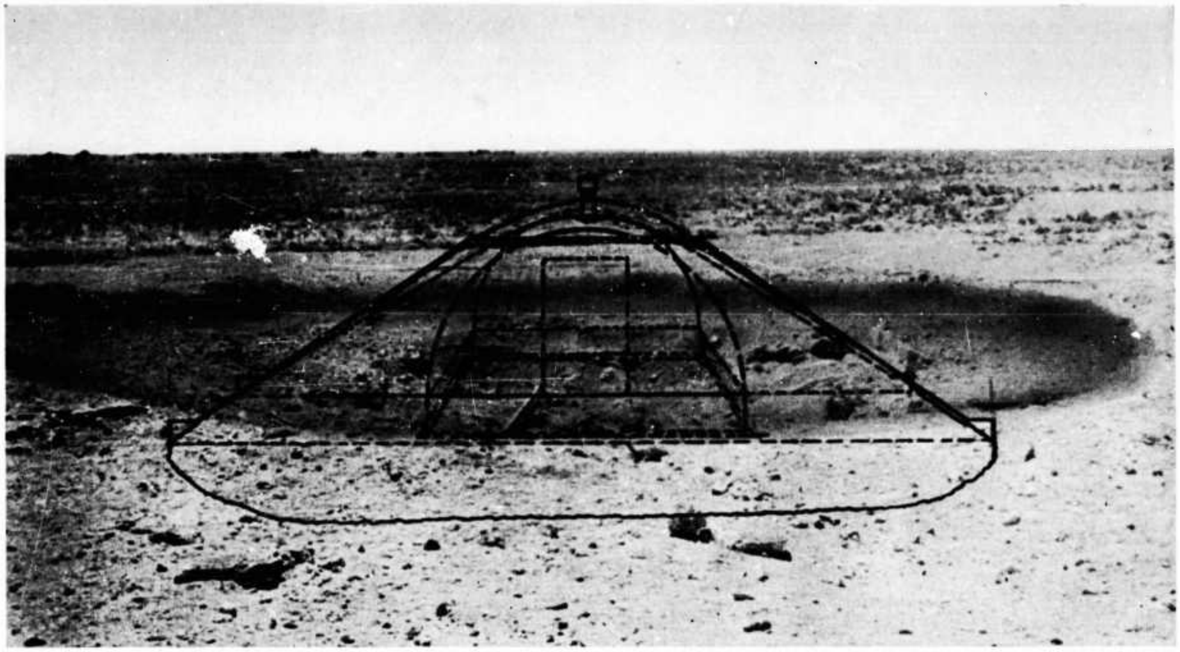


FIGURE 21. Crater, Test No. 1, with Igloo A superimposed in original location.

the center of the igloo. The maximum range of the heavier concentrations also lay along these lines, with a greater area of these concentrations lying in front (north) of Igloo A than behind it.

(2) The missile map shown in figure 54 was made on a grid system. A baseline was drawn along the front face of Igloo A perpendicular to the centerline of the igloo. Lines were then constructed perpendicular to the base line at fifty foot intervals starting with the center line of Igloo A. These lines were covered by two-men teams in jeeps. Each missile was recorded by its line number, distance from base line, and distance in feet east or west of the nearest line. The missiles were then plotted on a map of the area divided into 100 foot squares, and the number of missiles falling in each square was indicated without attempting to plot the missiles precisely. Lines of equal missile concentration were then drawn to produce the missile map shown in figure 54.

(3) A study of the missile map leads to the following observations:

(*a*) Missiles flew out farther along the center line axes of the igloo and were more concentrated along these lines.

(*b*) Greater concentrations occurred in front than to the rear of the igloo up to 1,500 feet. Beyond this distance distribution was uniform along the axes.

(*c*) Greater concentration occurred off the sides than in front or to rear from 250 to 1,500 feet, probably due to the door barricade which seemed to divert missiles toward the sides at this range although the door barricade apparently had little effect on general missile distribution.

(4) Fragmentation was very complete with missiles at the extreme range weighing from a few ounces to five pounds. No missiles were found exceeding 150 pounds in weight with the exception of a few large pieces of concrete lying in and adjacent to the crater.

(5) For the purpose of studying missile trajectory, twenty-five M-47 chemical bomb cases were sand filled and placed in the stacks with the H. E. bombs. Each bomb was numbered with a metal stamp in the hope that fragments from the bombs could be identified and, with the initial and final locations being known, some estimate of the trajectory could be made. Unfortunately, no identifiable fragments of these bombs were found.

i. Seismological data.

(1) Seismic records were obtained in this test by the Taylor Model Basin at distances up to 1 mile from the explosion. Additional data were

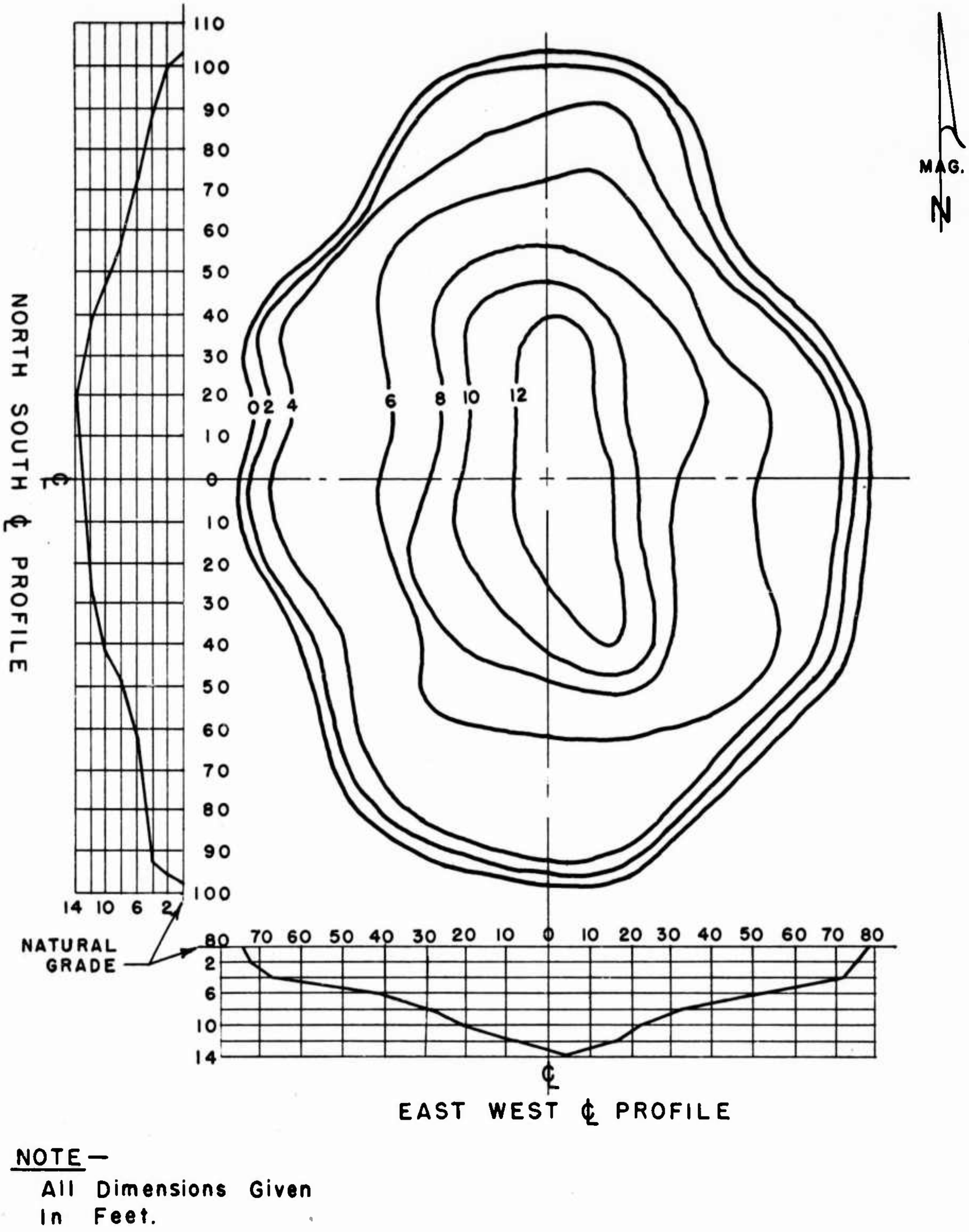


FIGURE 22. Crater plan and profiles, Igloo A, Test 1.

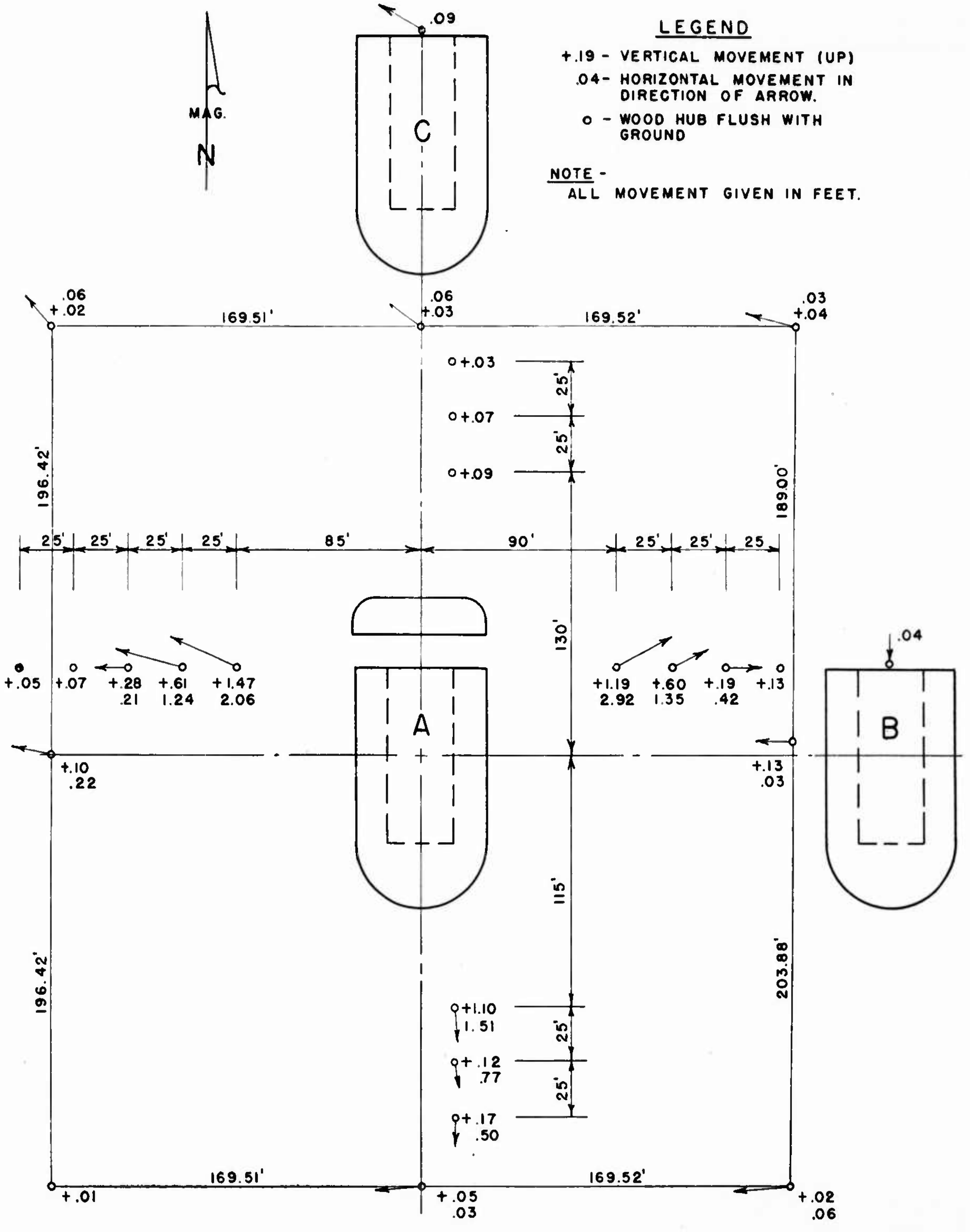


FIGURE 23. Permanent horizontal and vertical earth displacement, Test 1.

not obtained due to a power failure which prevented the operation of the instruments installed by the U. S. Coast and Geodetic Survey and the Bureau of Reclamation.

(2) *Results obtained by David Taylor Model Basin.*

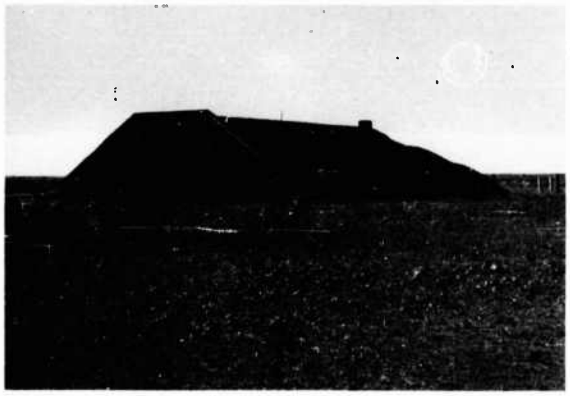


FIGURE 24. Target Igloo B, damage to earth cover and ventilator, Test 1

(*a*) Recording instruments used to measure earth movements were mounted on concrete piers constructed on an overburden of 10 to 15 feet, located at distances of ½ mile and 1 mile from the explosion (fig. 55, Dugouts 2 and 3). The TMB Type B parallelograph which was converted to an accelerometer with a natural frequency of 17 cycles per second was located at Dugout 2 and recorded horizontal accelerations. The TMB Type C parallelograph, which is a seismic instrument used to record horizontal displacements was located at Dugout 3.

(*b*) In addition to the above, five mass-plug accelerometers were mounted on a concrete pier 150 feet east of Igloo A as shown in figure 55. The mass-plug accelerometer consists of a mass supported by a bakelite plug, a portion of which is turned down to a diameter such that it will break when the mass is subjected to the approximate acceleration for which the plug was designed. A 1,000-g. and a 500-g. accelerometer were mounted in a horizontal plane in line with the

FIGURE 25. Target Igloo C, door damage, Test 1.

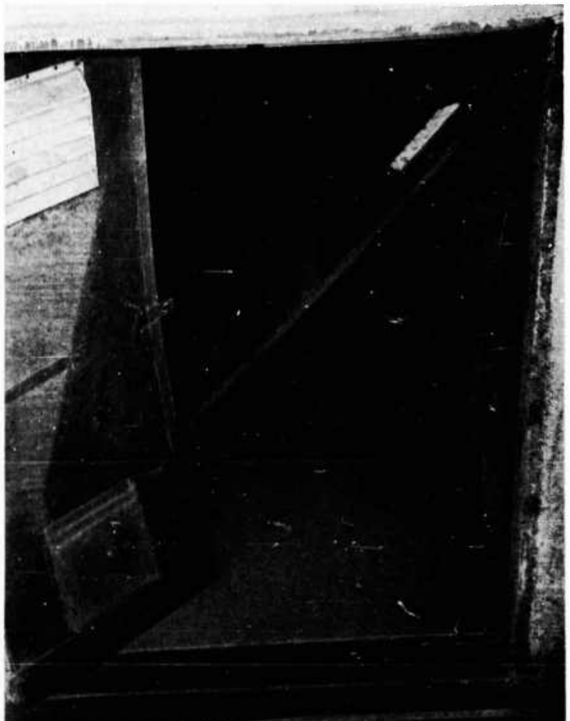


FIGURE 26. Target Igloo D, door damage, Test 1.

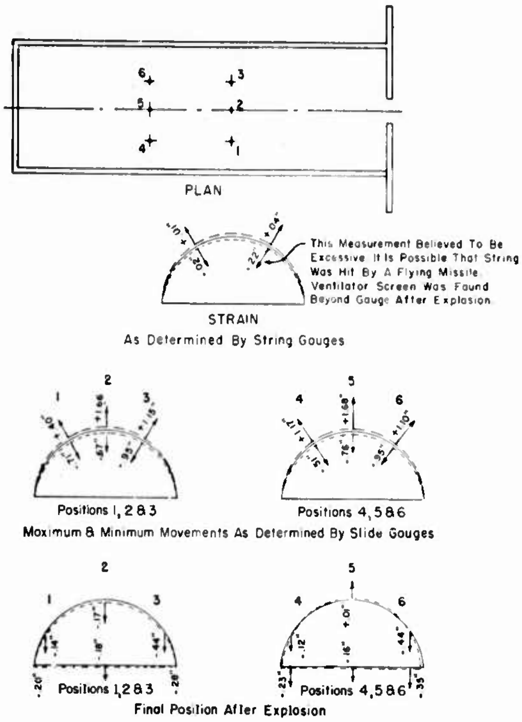


Figure 27a. Maximum and minimum igloo movement, Igloo B.

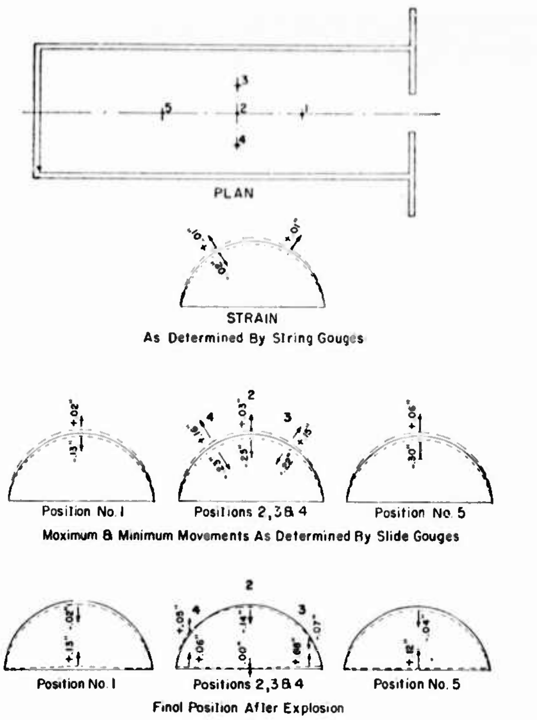


Figure 27b. Maximum and minimum igloo movement, Igloo C.

blast; a 500-g. and a 300-g. accelerometer were mounted in a horizontal plane perpendicular to the blast; and a 300-g. accelerometer was mounted in a vertical position. These mass-plug accelerometers were mounted in such a way as to respond only to earth movement and not to the air shock.

(c) The following results were obtained:

1. TMB Type B Parallelograph, Dugout 2 (½ mile), acceleration 0.25 g, frequency 11 c. p. s.

2. TMB Type C Parallelograph, Dugout 3 (1 mile), amplitude 0.015″, frequency 4.7 c. p. s.

3. Mass-plug accelerometers—none of the plugs were broken. Acceleration in the direction of the blast less than 500-g. Acceleration in the horizontal and vertical planes perpendicular to the direction of the blast—less than 300-g.

(d) It should be noted that the instruments measured the movement of the concrete piers on which they were located. The piers at Dugouts 2 and 3 apparently moved with the earth because

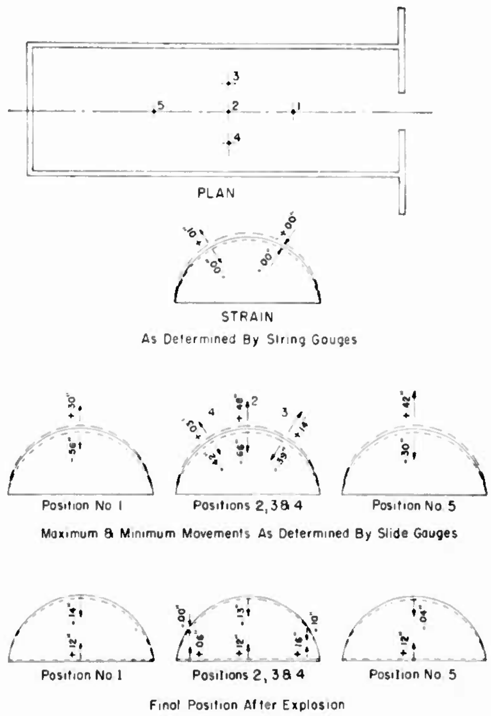


Figure 27c. Maximum and minimum igloo movement, Igloo D.

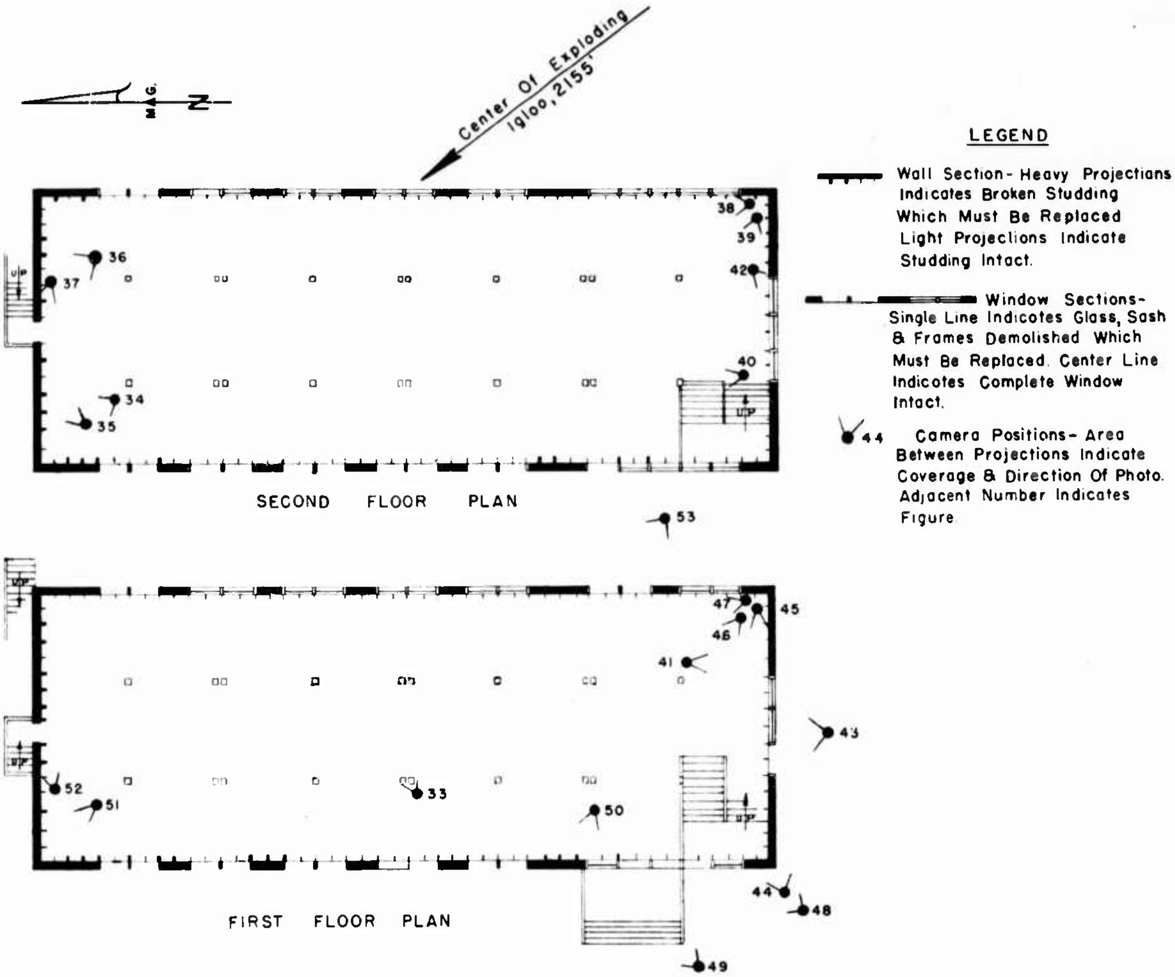


FIGURE 28. Barracks building damage. Legend to photos, Test 1.

the frequencies recorded by the instruments were well below the probable natural frequencies of the pier-earth system. On the other hand, the forced vibration of the earth movement experienced at the pier supporting the mass-plug accelerometers may have been of higher frequency than the natural frequency of the pier-earth system because of its proximity to the blast. If the forced frequency were considerably higher than the natural frequency of the system, the pier would tend to act as a seismic mass, and the mass-plug accelerometers would, therefore, not measure the true acceleration of the adjacent earth.

j. Meteorological records (Ref. 5).—The detonation of a very large quantity of explosives under test conditions afforded an excellent opportunity to measure the resulting meteorological phenomena under circumstances as close to laboratory conditions as possible. The meteorological observations consisted of (a) those taken in the vicinity of the test, and (b) those secured by voluntary, cooperative observers in the Western States, who had been requested through newspaper and radio announcements to listen for the explosion and forward an account to the Weather Bureau, Washington, D. C.

(1) *Instrumentation.*—The arrangement of the equipment used at the scene of the explosion is shown in figure 56. A theodolite and a microbarograph were located at Station W; a theodolite and a camera were located at Station E; and a microbarograph and a radiosonde unit were located at the Army Weather Station. In addition to the above, two Benioff electromagnetic barographs

FIGURE 29. Barracks damage, Test 1. West elevation (exposed to blast).

FIGURE 30. Barracks damage, Test 1. North elevation (exposed to blast).

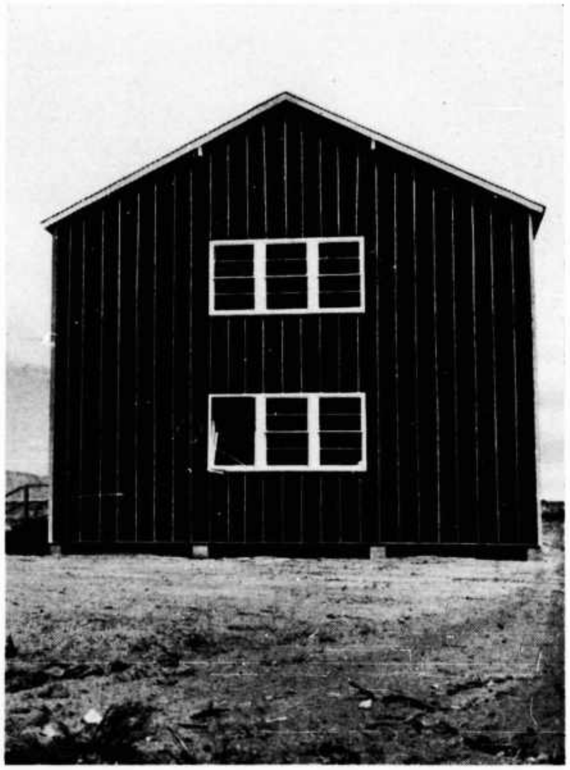


FIGURE 31. Barracks damage, Test 1. South elevation (away from blast).

FIGURE 32. Barracks damage, Test 1. East elevation (away from blast).

FIGURE 33. Barracks damage, Test

FIGURE 34. Barracks damage, Test 1.

FIGURE 35. Barracks damage, Test 1.

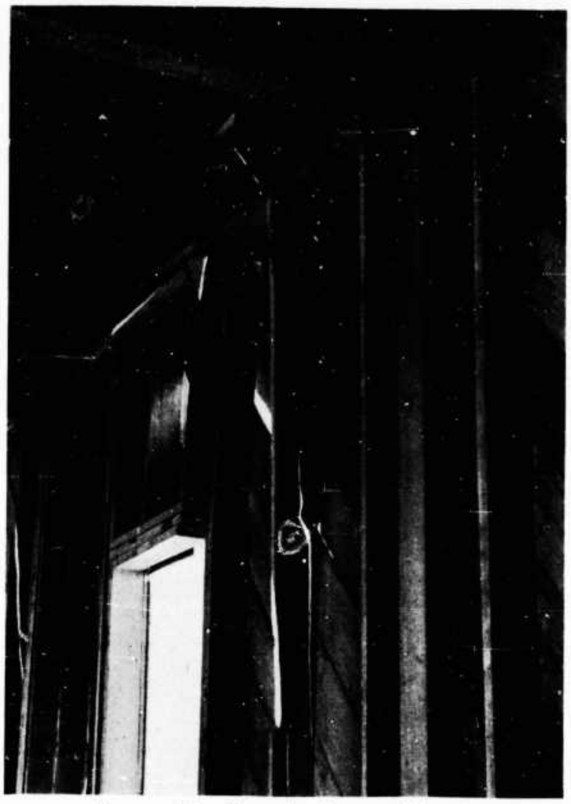


FIGURE 36. Barracks damage, Test 1.

FIGURE 37. Barracks damage, Test 1.

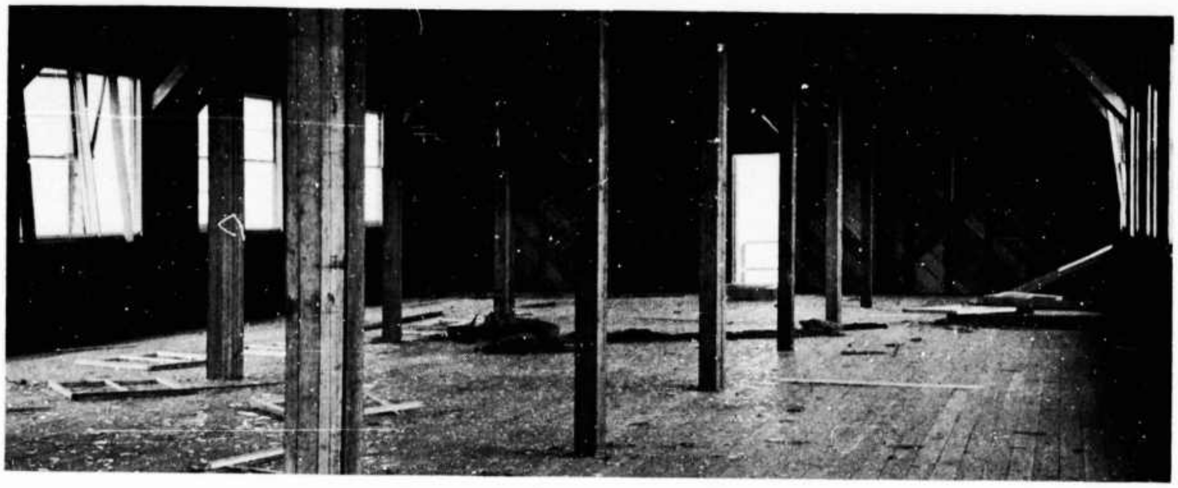


FIGURE 38. Barracks damage, Test 1.

FIGURE 39. Barracks damage, Test 1.

FIGURE 40. Barracks damage, Test 1.

FIGURE 41. Barracks damage, Test 1.

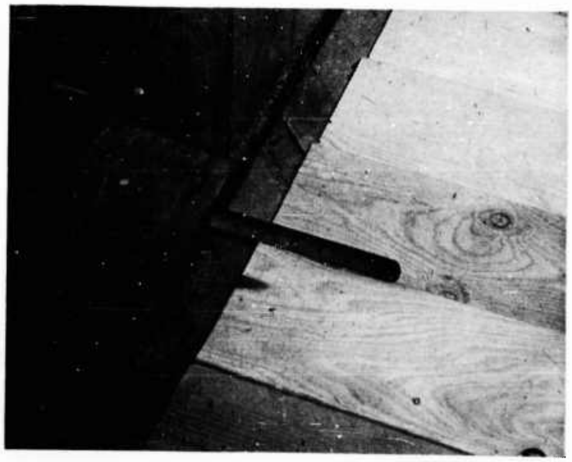


FIGURE 42. Barracks damage, Test 1.

FIGURE 43. Barracks damage, Test 1.

FIGURE 44. Barracks damage, Test 1.

FIGURE 45. Barracks damage, Test 1.

FIGURE 46. Barracks damage, Test 1.

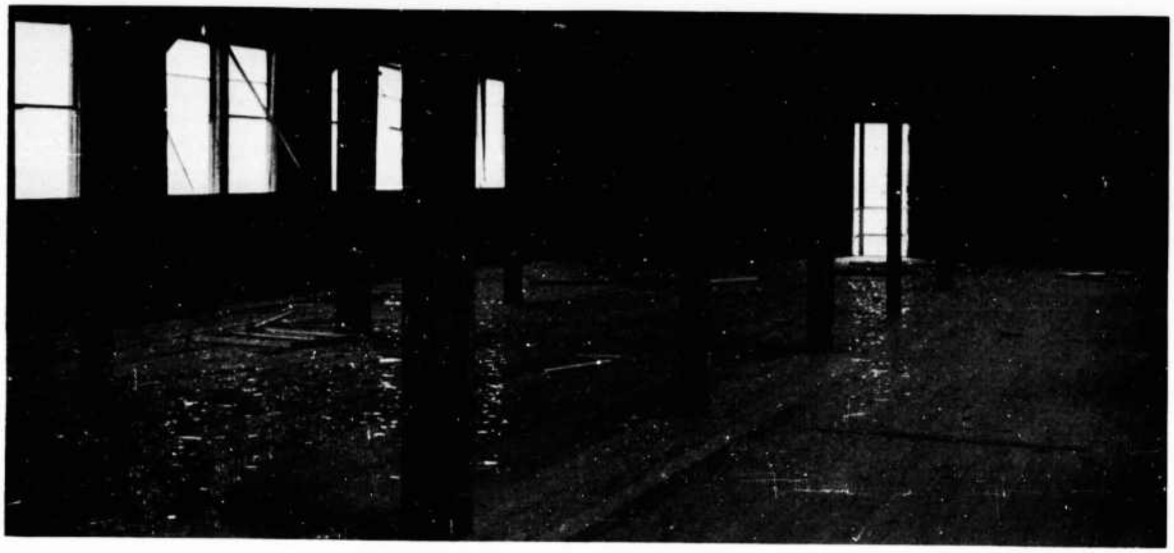


FIGURE 47. Barracks damage, Test 1.

FIGURE 48. Barracks damage, Test 1.

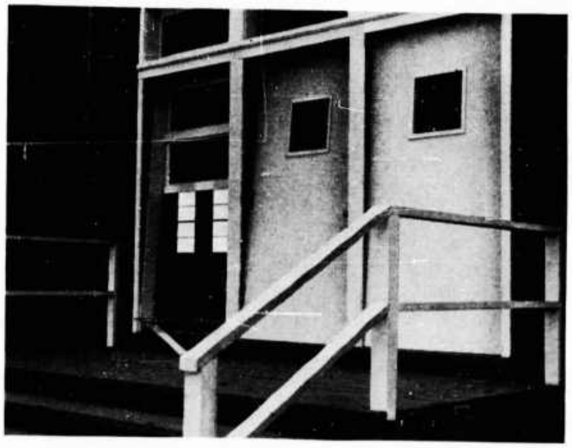


FIGURE 49. Barracks damage, Test 1.

FIGURE 50. Barracks damage, Test 1.

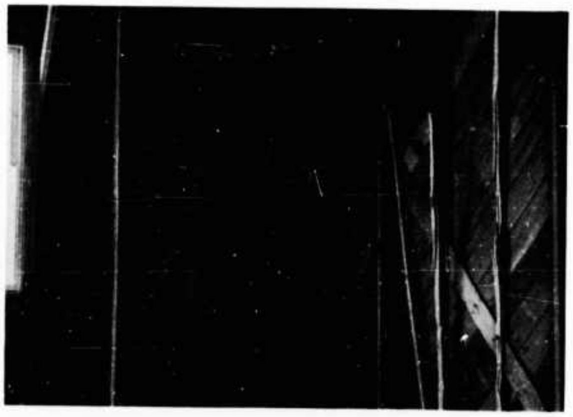


FIGURE 51. Barracks damage, Test 1.

FIGURE 52. Barracks damage, Test 1.

FIGURE 53. Barracks damage, Test 1.

(described in Ref. 6) were used. One barograph was placed at Dubois, Idaho (49.6 miles) and the other at West Yellowstone, Mont. (111.2 miles).

(2) *Results.*

(*a*) Theodolite observations made at Stations E and W were used to determine the height of the dust and smoke cloud (table IX). The cloud reached its maximum height of 2,380 feet 2 minutes after the explosion.

(*b*) The microbarograph records made at Station W and the Army Weather Station are shown in figures 57a and 57b.

(*c*) The electromagnetic barograph records are shown in figure 58. Time interruptions of the light beam were made manually in synchronism with aural signals received by radio from Station ANB. The pressure phenomena began at Dubois at 0933+50″ and ended at 0933+56″ giving 1,138.6 feet per second and 1,109.7 feet per second, respectively. The pressure wave phenomena began at West Yellowstone at 0938+28″ and ended at 0938+31″ giving sound speeds of 1,158.8 feet per second and 1,149.0 feet per second, respectively.

(*d*) The radiosonde observation taken at 0930 MWT is shown in figure 59. An isothermal layer extends from the surface at 16° C. to 131 feet above ground; an inversion of 18° C. at 1,476 feet above ground; and an isothermal layer, 18° C.

TABLE IX.—*Two theodolite observations*

[Station: Naval Proving Ground, Arco, Idaho. Date: Aug. 29, 1945. Starting time: 0930 MWT]

Observation point: Station W. Zero setting on Station E. Observer: A. W. Anderson

Minute	Elevation angle	W azimuth angle*	Distance from observation point (ft.)	Altitude (ft.)
1	10. 0	275. 9	11, 760	2, 070
2	11. 2	277. 1	12, 030	2, 380
3	12. 8	277. 1	10, 160	2, 290
4	------	------	------	------
5	9. 4	139. 2	6, 940	1, 150

Observation point: Station E. *Zero setting on Station W. Observer: J. Travis

Minute	Elevation angle	W azimuth angle*	Distance from observation point (ft.)	Altitude (ft.)	Azimuth angle W-E
1	9. 1	241. 8	13, 260	2, 120	34. 1
2	9. 95	243. 3	13, 350	2, 340	33. 8
3	10. 9	238. 1	11, 800	2, 270	39. 0
4	------	------	------	------	------
5	12. 5	243. 9	5, 050	1, 120	104. 7

Base line = 7,480 feet

*These azimuth angles were increased 180° for proper orientation.

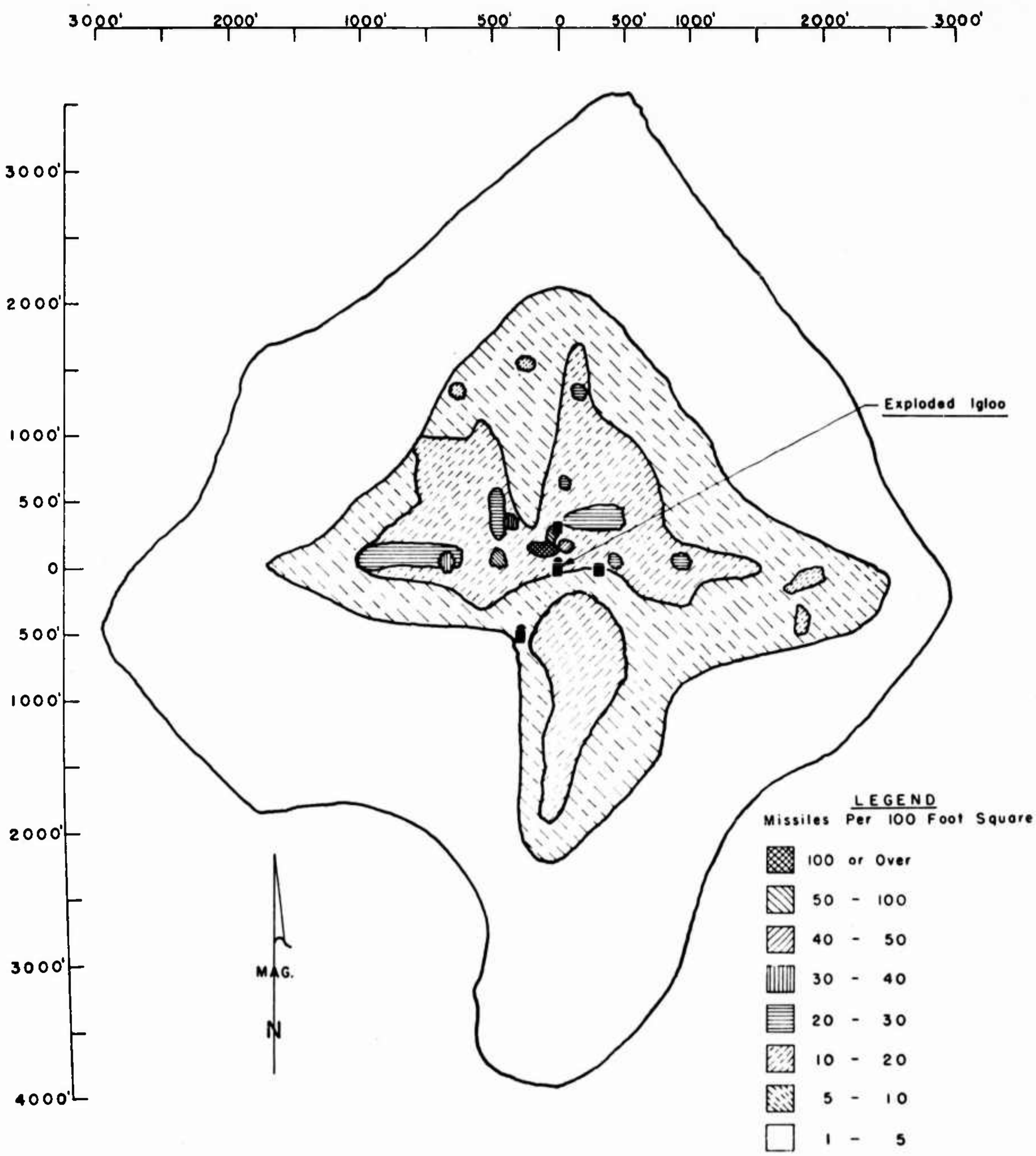


FIGURE 54. Missile map, Test 1.

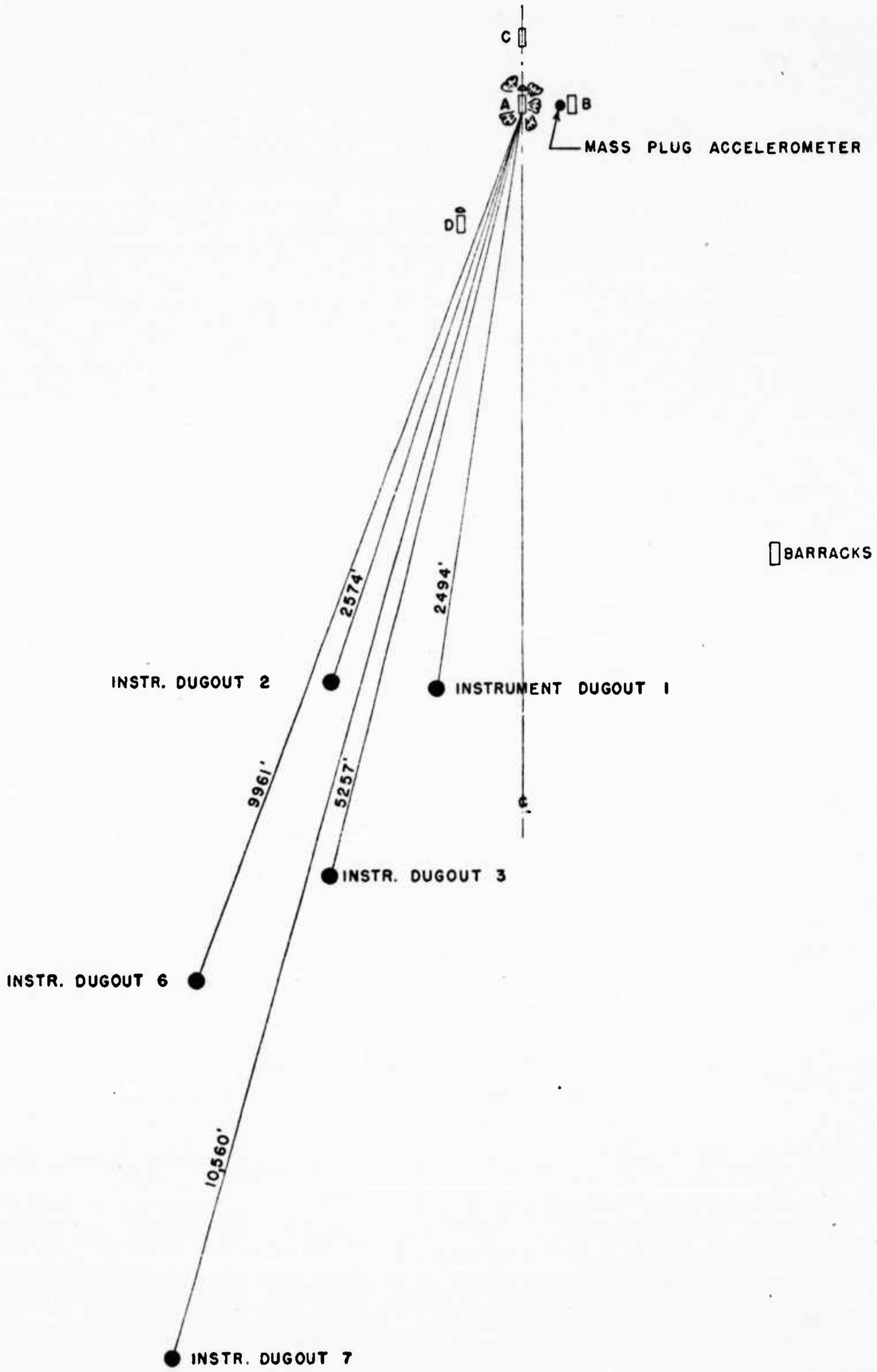


FIGURE 55. Layout of seismic instruments.

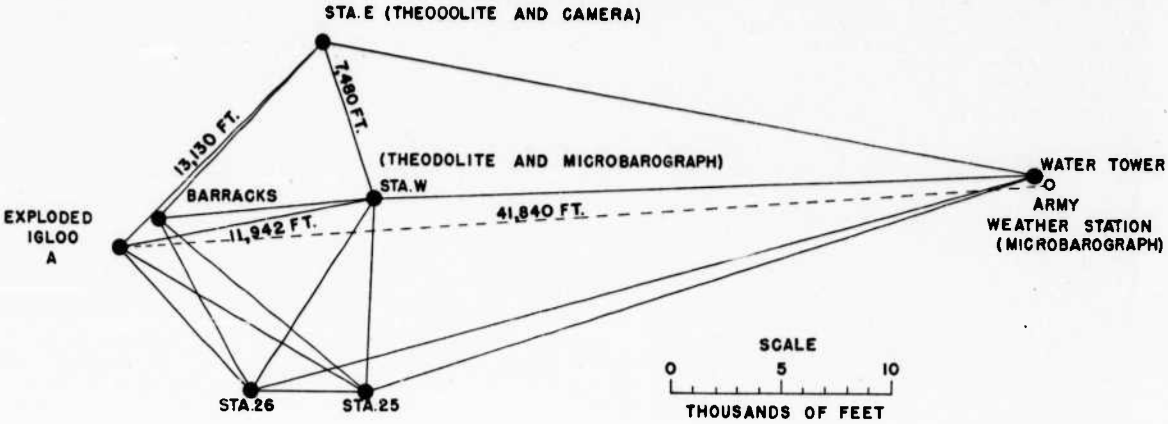


FIGURE 56. Layout of meteorological stations, Test 1.

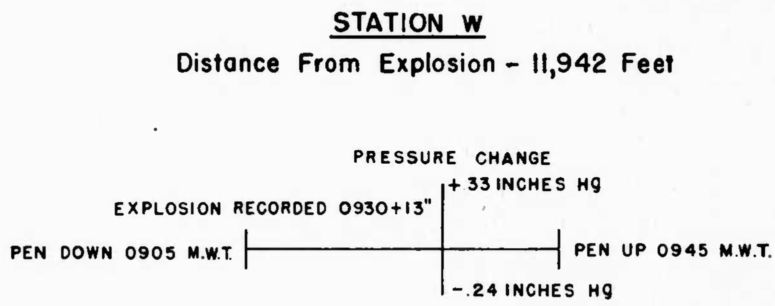


FIGURE 57a. Pressure changes at 11,942 feet, Test 1.

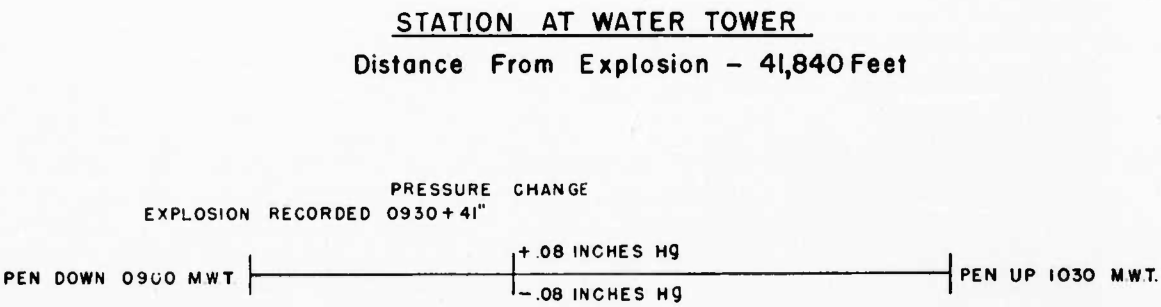
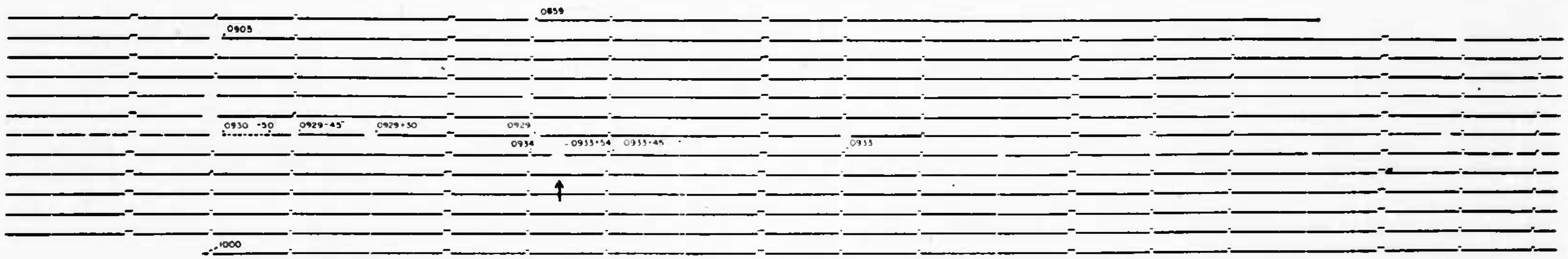


FIGURE 57b. Pressure changes at 41,840 feet, Test 1.



LOCATION: DUBOIS, IDAHO
LATITUDE 44° 10′ North, LONGITUDE 112° 18′ West; ELEVATION 5,122 Feet
DISTANCE FROM EXPLOSION 49.6 Miles (261,888 Feet)

LOCATION: WEST YELLOWSTONE, MONT.
LATITUDE 44° 39′ North; LONGITUDE 111° 06′ West; ELEVATION 6,669 Feet
DISTANCE FROM EXPLOSION 111.2 Miles (587,136 Feet)

FIGURE 58. Ground waves recorded by barograph, Test 1.

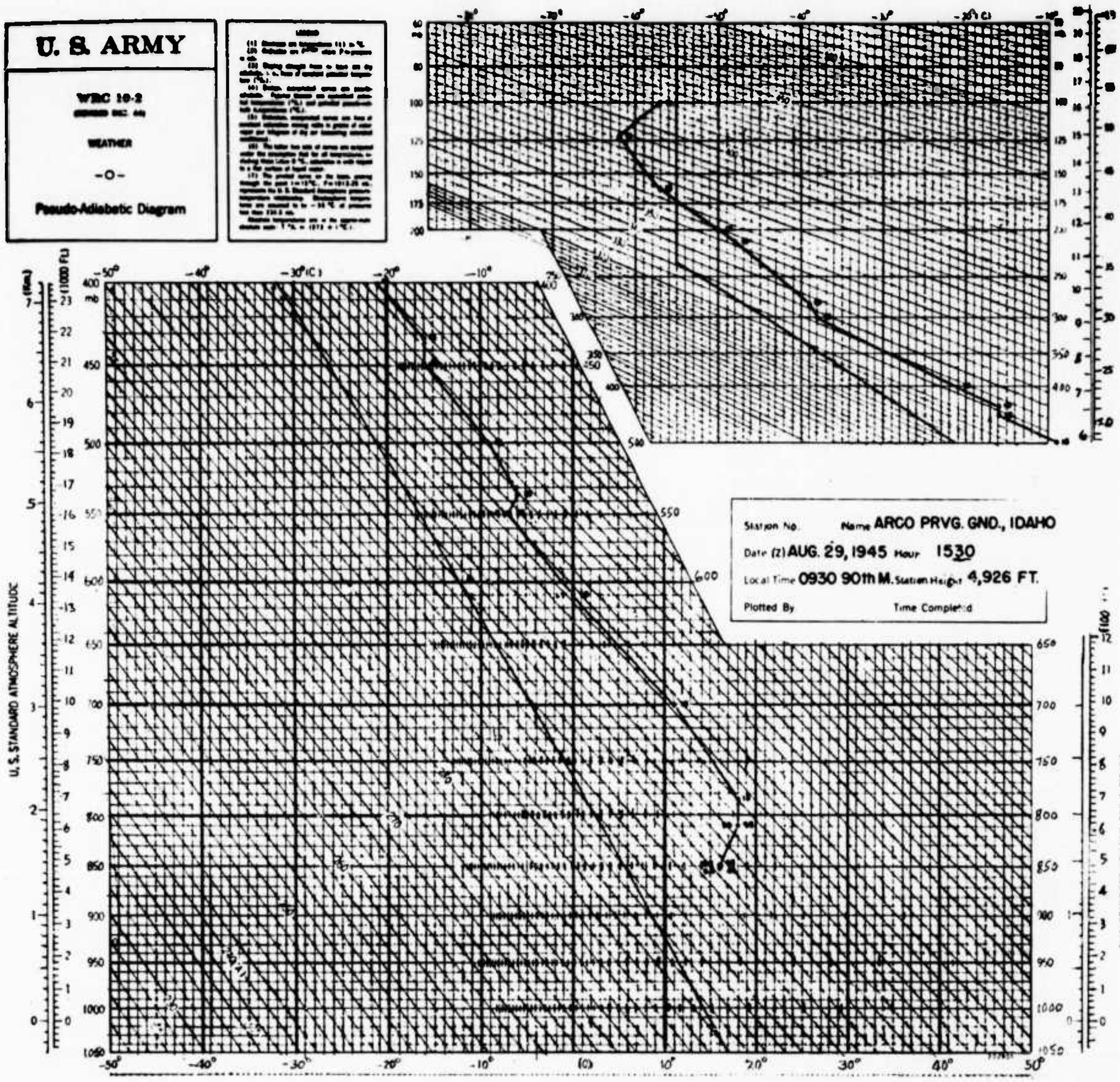


FIGURE 59. Radiosonde observations, Test 1.

to 2,221 feet above the ground. At this level temperature begins to fall at a lapse rate of 0.72° C. per 100 meters.

(*e*) The winds aloft observation taken by a single theodolite observation of the radiosonde balloon at 0930 MWT is shown in figure 60. In the lower layers the wind was NE 4 mph up to 900 feet above the ground, shifting to SW 4 mph at 1,600 feet above the ground, and increasing to SW 18 mph at 4,900 feet.

(*f*) Surface observations taken from 0230 MWT to 1030 MWT at the Army Mobile Weather Station are shown in figure 61. Following is the observation at 0930 MWT: sky clear; visibility, 50 miles; sea level pressure, 1,017 millibars; temperature, 60°; dew point 49° F.; wind NE 4 mph. Surface pressure taken from radiosonde 854 millibars.

(*g*) The aural observations of the sound caused by the explosion are plotted in figure 62 and explained in the accompanying table X. A total of 706 reports were received, of which 73 reported hearing the explosion.

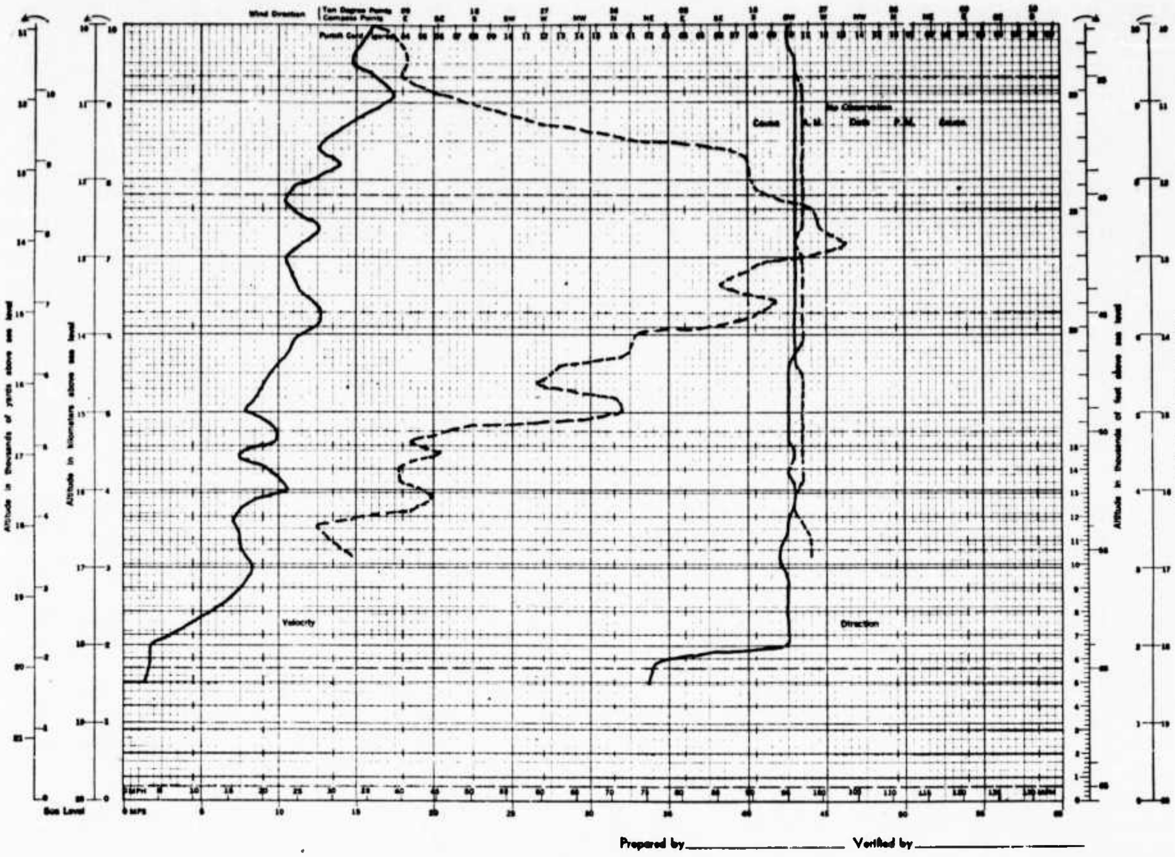


FIGURE 60. Winds aloft record.

TYPE (1)	TIME (2)	CLASSIFICATION (3)	CEILING (4)	SKY (5)	VISIBILITY (Miles) (6)	WEATHER AND/OR OBSTRUCTIONS TO VISION (7)	SEA-LEVEL PRESSURE (Mbs.) (8)	TEMP. AND DEW PT. (°F) (9)	(10)	WIND DIRECTION (11)	VELOCITY (M.P.H.) (12)	CHARACTER AND SHIFTS (13)	ALTIMETER (Inches) (14)	REMARKS AND SUPPLEMENTAL CODED DATA (For Transmission) (15)	PRES. TEND. (16)	NET 3-HR. CHANGE (17)
R	0230			0	30		1019	48	31	S	4					
R	0330			0	30		1019	49	25	S	2					
R	0430			0	30		1020	46	25	NW	2			3 c 4		
R	1530			0	30		1020	46	31	NW	4					
R	1630			0	30		1021	46	33	NW	3					
R	0830			0	50		1019	56	46	NE	3					
R	0930			0	50		1017	60	49	NE	4					
R	1030			0	50		1013	72	53	NE	5			VSBY 2 MI SW DUE SMOKE AND DUST CLOUD FEW ALTOCU SE QUAD		

Month AUGUST Day 29 Year 1945

SC Form No. 426
1 November 1944

Time entries on this form are 90 th meridian time

To convert to G. C. T. {add / subtract} 6 hours

Height of Barometer 4926 Ft. (MSL)

Security Classification ____________

Station ARCO PROVING GROUND

Lat. 42°39'N Long. 113°18'W

U. S. ARMY WEATHER SERVICE

SURFACE WEATHER OBSERVATIONS

(LAND STATION)

WBAN—10A

FIGURE 61. Surface weather observations.

TABLE X.—*Aural reports of explosion, Test 1, Naval Proving Ground, Arco, Idaho, 9:30 a. m., MWT, 29 August 1945*

No.	Observation point	Latitude		Longitude		Not heard	Heard time MWT	Remarks
		°	'	°	'			
1	Roseville, Calif	38	45	121	20		10:07	Roar.
2	Acampo, Calif	38	15	121	30		10:15	Boom.
3	Menlo Park, Calif	37	25	122	15	x		
4	Sausalito, Calif	37	50	122	30		10:30	Faint boom.
5	Coronado, Calif	32	40	117	10	x		
6	Coalinga, Calif	36	09	120	21		10:35	Sharp jar.
7	Alturas, Calif	41	25	120	30	x		
8	Saratoga, Calif	37	15	122	00	x		
9	Porterville, Calif	36	02	119	00		10:26	Hard bang of door.
10	San Francisco, Calif					x		
11	Oakland, Calif						10:31	Windows vibrated.
12	do						10:45	Low long-toned rumbles.
13	San Francisco, Calif						10:15	
14	do						10:20	
15	do					x		
16	Three Forks, Mont	45	53	111	30		09:52	Very loud.
17	AAF Depot, Ogden, Utah	41	12	112	01	x		
18	Salt Lake City, Utah						09:46	Like dumping dirt.
19	do						10:55	Like a blast.
20	Lofgreen, Utah	40	01	112	30		10:10	Large blast at distance.
21	Murray, Utah	40	40	111	55		09:38	Like a shotgun.
22	Tooele, Utah	40	30	112	20		10:09	Distant thunder.
23	Magna, Utah	40	45	112	10		10:17	Fairly loud.
24	Chehalis, Wash	46	40	123	00	x		
25	Mirror Lake, Wash	47	10	122	30	x		
26	Portland, Oreg	45	32	122	40	x		
27	Rainier, Oreg	46	05	122	55	x		
28	Elgin, Oreg	45	30	117	56	x		
29	Walla Walla, Wash	46	04	118	20		09:50	Charge of dynamite.
30	Washtucna, Wash	46	45	118	20		09:43	Heard plainly.
31	Firth, Idaho	43	15	112	08		09:33. 5	Low rumble.
32	do	43	15	112	08		09:34	Barely heard.
33	Blackfoot, Idaho	43	15	112	15		09:37	2 claps of thunder.
34	Firth, Idaho	43	18	112	05		09:33	2 distant blasts.
35	Shelley, Idaho	43	20	112	15		09:34	2 explosions (not loud).
36	do	43	18	112	08		09:33	Smelled powder, saw smoke, heard faint noise.
37	do	43	20	112	08		09:34	Distant roar.
38	Idaho Falls, Idaho	43	30	112	04	x		House shook—09:34.
39	do	43	40	112	02		09:33. 5	Medium loud.
40	do	43	29	112	08		09:32. 5	Muffled blast—2.
41	Lorenzo, Idaho	43	40	111	55		09:34	Clearly heard.
43	Rexburg, Idaho	43	50	111	56		09:32. 5	Distant thunder roar.
44	St. Anthony, Idaho	43	57	111	48		09:36	Shook house.
45	Blackfoot, Idaho	43	30	113	03		x	Saw smoke—2 explosions.
46	Arco, Idaho						x	Thump.
47	Idaho Falls, Idaho	43	38	112	00		09:35	House shook.
48	Sweet, Idaho	46	00	116	18		09:46	Blast.
49	Terreton, Idaho	43	50	112	30		x	Three blasts.
50	Malad, Idaho	42	08	112	06	x		
51	Donnelly, Idaho	44	42	116	05		09:45	2 short rumbles.
52	Pine, Idaho	43	38	115	20		09:44	Distant thunder.
53	Idaho Falls, Idaho	43	28	112	08		09:35	Like distant thunder.
54	Rigby, Idaho	43	39	112	00		09:38	Like thunder.
55	Castleford, Idaho	42	30	115	00		x	2 muffled sounds.
56	Filer, Idaho	42	32	114	37		09:41	Charge of dynamite.
57	Rexburg, Idaho	43	49	111	50		09:37	Slight jar—3 sharp raps.
58	Idaho Falls, Idaho	43	28	112	15		09:35	Blast.
59	do	43	27	111	56		09:31	Quite loud—saw smoke.
60	Shelley, Idaho	43	20	112	05		09:32	Like distant thunder.
61	Rexburg, Idaho	43	49	111	50		09:35	Doors rattled.
62	Boise, Idaho	43	31	116	00		09:45	Loud boom.
63	Idaho Falls, Idaho	43	25	112	05	x		Rattled doors—09:36.
64	Rexburg, Idaho	43	48	111	40		09:35	Doors rattled.
65	Bonners Ferry, Idaho	48	40	116	20		09:53	Low rumbling blast.
66	Firth, Idaho	43	19	112	11		09:32. 5	Dull shot, shook doors.
68	Rexburg, Idaho	43	45	111	50		09:30	Roar like thunder.
69	Culp Creek, Oreg	43	45	122	50		10:00	Like dynamite.
70	Medford, Oreg						10:50	Like morning salute.
71	Berkeley, Calif					x		
72	Cherryville, Oreg						10:30	Distinct, fairly loud.
73	Newport, Oreg						09:55	Very dull sound.
74	Waldport, Oreg						09:40	Came from ocean side.

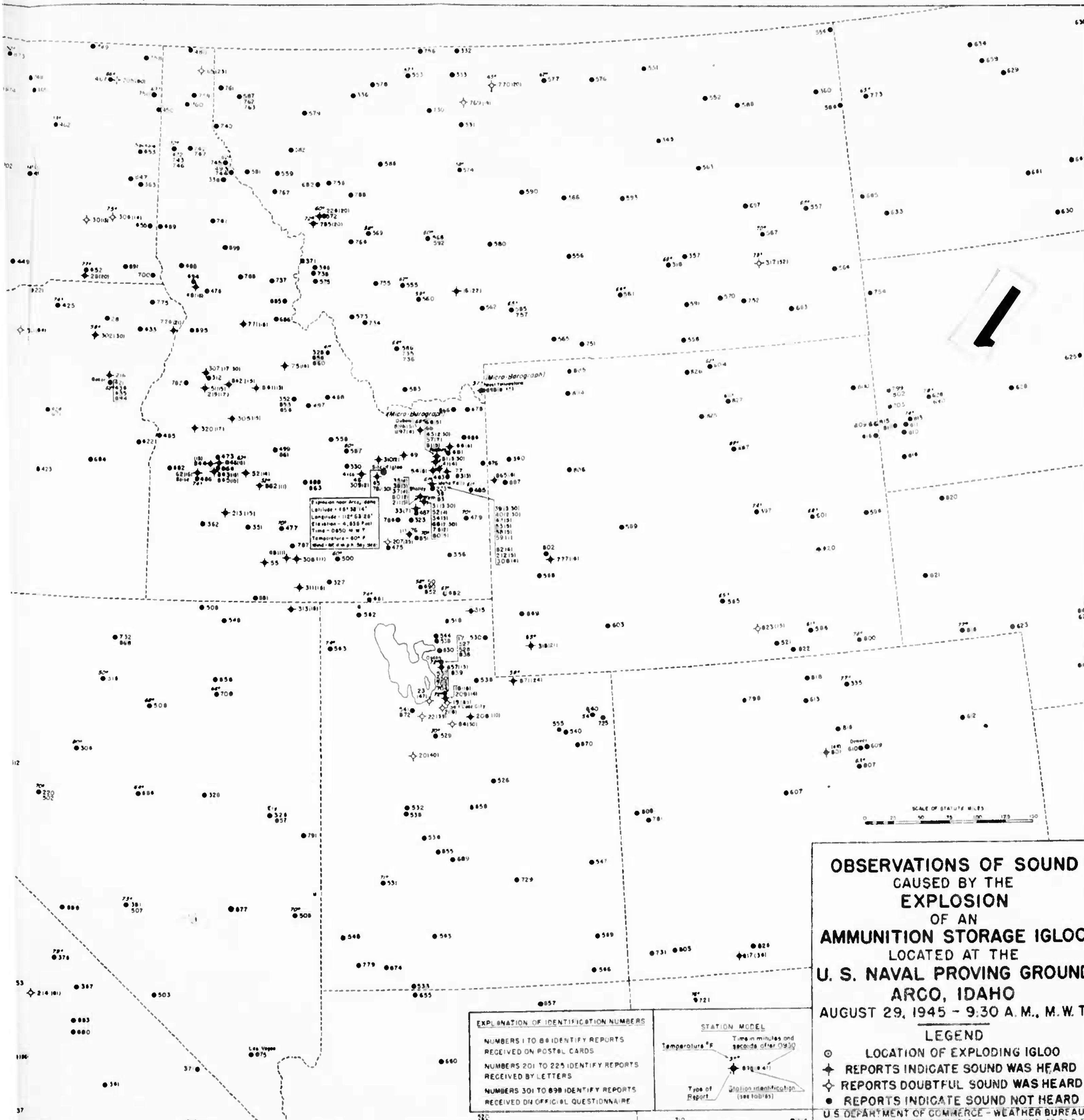


FIGURE 62. Observations of sound caused by the explosion.

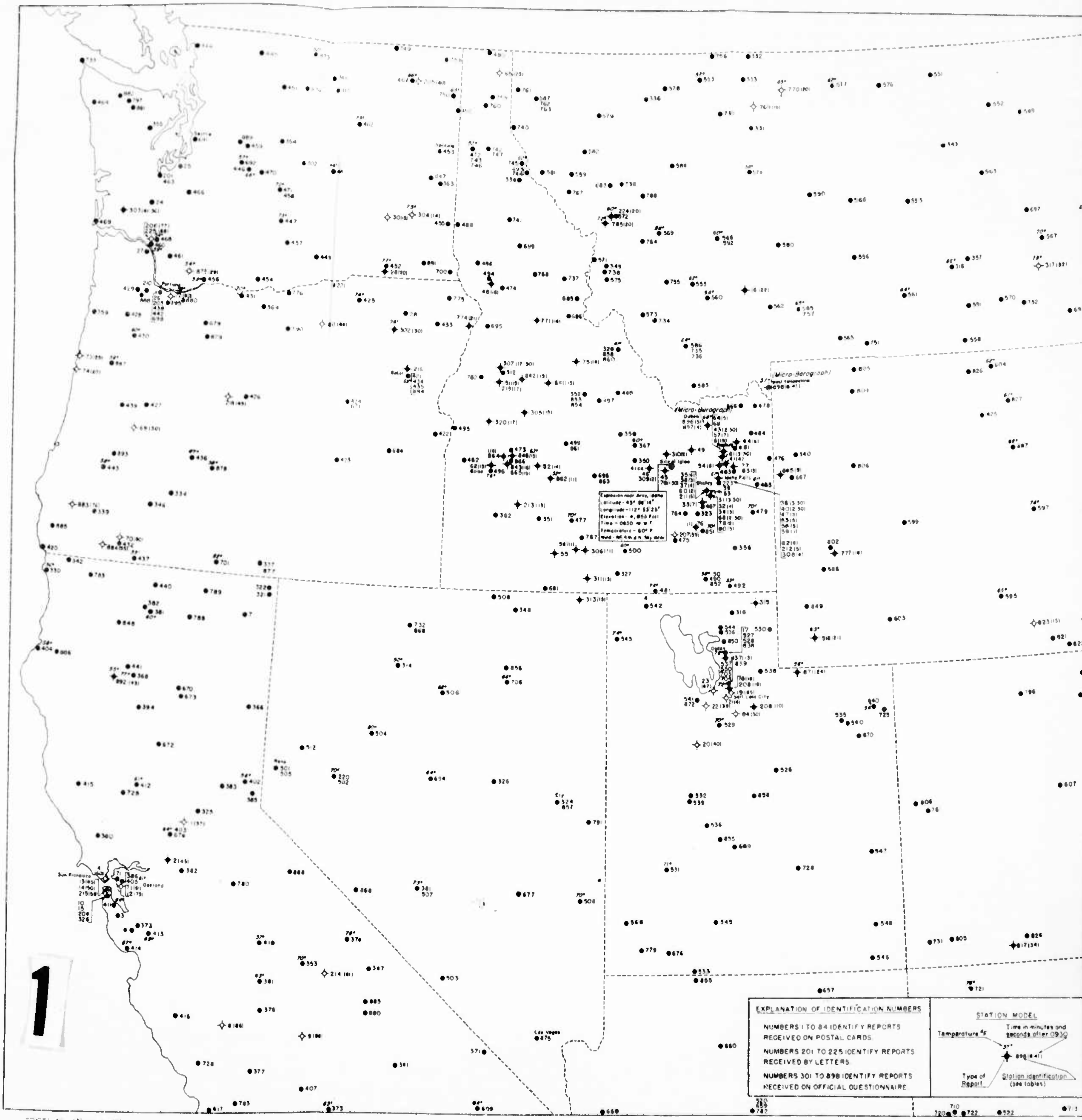


FIGURE 62. Observations of sound caused by the explosion.

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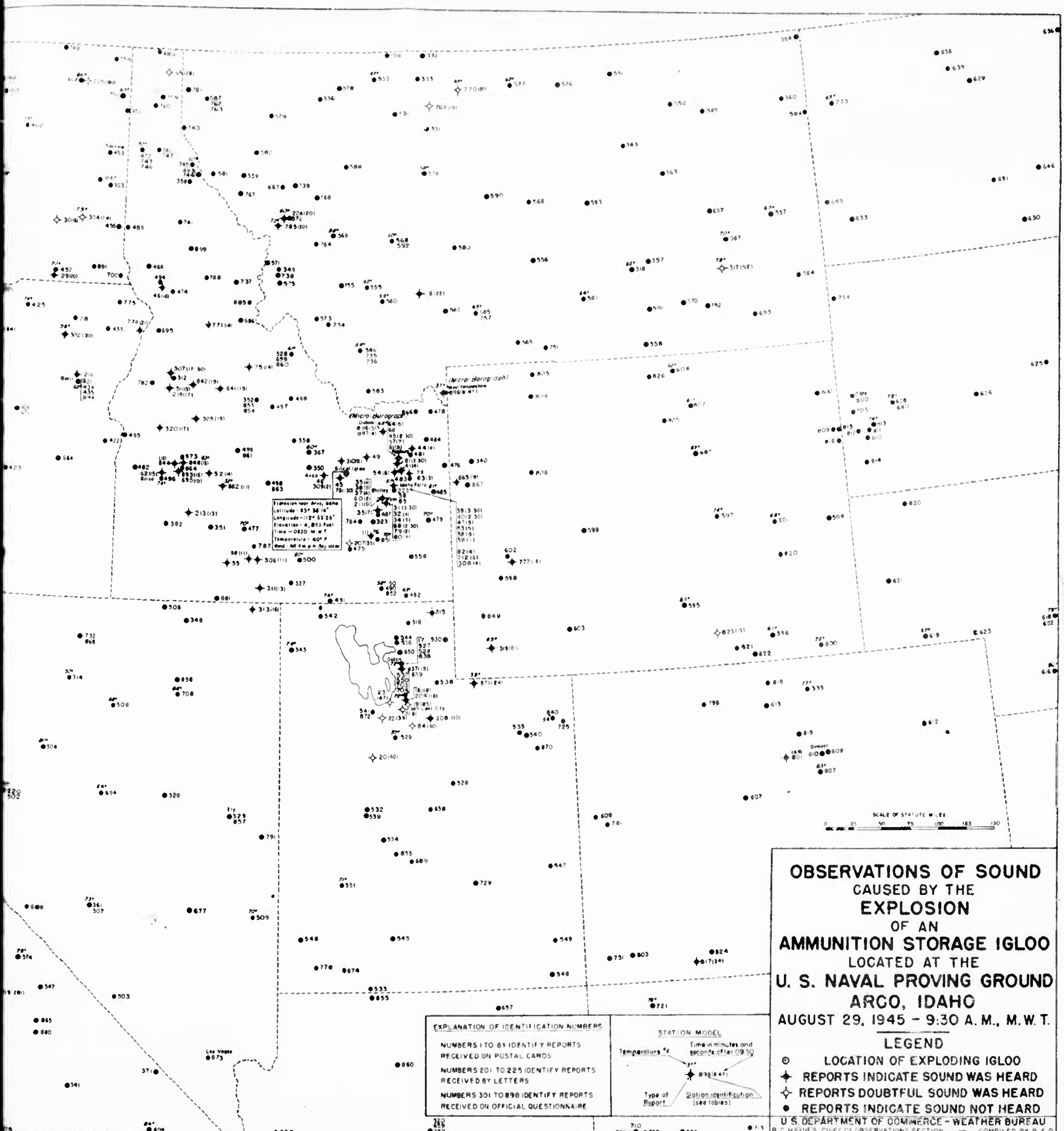

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FIGURE 62. Observations of sound caused by the explosion.

TABLE X.—*Aural reports of explosion, Test 1, Naval Proving Ground, Arco, Idaho, 9:30 a. m., MWT, 29 August 1945*—Con.

No.	Observation point	Latitude °	Latitude ′	Longitude °	Longitude ′	Not heard	Heard time MWT	Remarks
75	Forney, Idaho	45	00	114	40		09:44	
76	Pocatello, Idaho						09:31	
77	Rigby, Idaho						09:30	Light blast.
78	Blackfoot, Idaho	45	45	112	51		09:31. 5	Loud distant thunder.
79	Firth, Idaho						09:32	Big blast.
80	do						09:35	Distinct heavy thump.
81	Thronton, Idaho						09:33. 5	Dull rumble—2.
82	Idaho Falls, Idaho						09:36	Rattled windows.
83	Rigby, Idaho						09:33	
84	Pleasant Grove, Utah						10:00	
*	*	*		*		*	*	*
201	Olympia, Wash					x		
202	Winnipeg, Manitoba					x		
203	Portland, Oreg					x		
204	San Francisco, Calif					x		
205	Colville, Wash	48	40	117	45		10:50	Like a gun sound.
206	Longview, Wash	46	10	122	55		10:47	Distinct sound.
207	American Falls, Idaho						10:05	Blast.
208	Heber, Utah						09:40	Distinct clang.
209	Salt Lake City, Utah						09:49	Like loud thunder.
210	Hillsboro, Oreg					x		Rattled windows.
211	Shelley, Idaho						09:35	Low rumble.
212	Idaho Falls, Idaho						09:35	Muffled shot.
213	Mountain Home, Idaho						09:43	Dynamite charge.
214	Kings Canyon National Park, Calif						10:51	Loud sharp report.
215	San Francisco, Calif						10:28	Slight jar.
216	Baker, Oreg						x	Distant but distinct.
217	Powell River, British Columbia						x	
218	Redmond, Oreg	44	15	121	10		10:15	
219	Donnelly, Idaho	44	40	116	05		09:47	2 explosions.
220	Fallon, Nev	39	30	118	40	x		
221	Herniston, Oreg	45	50	119	20	x		
222	Phoenix, Ariz					x		
223	Idaho Falls, Idaho					x		
224	Missoula, Mont						09:50	Boom.
225	Longview, Wash						10:38	2 reports.
*	*	*		*		*	*	*
301	Mount Laguna, Calif	32	52	116	25		10:32	Faint rumble.
302	La Grande, Oreg	45	17	118	20		10:00	Distant thunder.
303	Lebam, Wash	46	32	123	31		10:11. 5	3 distinct rumbles followed by a blast.
304	Lacrosse, Wash	46	49	117	53		09:44	Like distinct rumbles.
305	Deadwood Dam, Idaho	44	19	115	39		09:45	2 light, 2 loud.
306	Twin Falls, Idaho	42	33	114	28		09:41	Light sound.
307	McCall, Idaho	44	54	116	06		09:47. 5	Distant thunder—2.
308	Idaho Falls, Idaho	43	31	112	03		09:34	Weak rumble.
309	Arco (1 mile), Idaho	43	39	113	18		09:32	Rumble.
310	Howe, Idaho	43	46	113	00		09:32	2 blasts, then echo.
311	Rock Creek Ranger Station, Idaho	42	12	114	20		09:43	2 explosions.
312	McCall, Idaho					x		
313	San Jacinto, Nev	41	55	114	29		09:45	2 distinct rumbles.
314	Winnemucca, Nev	40	58	117	43	x		
315	Laketown, Utah	41	49	111	19		x	
316	Logan, Utah	41	44	111	49	x		
317	Garland, Mont	46	02	105	56		10:22	Dull thud.
318	Custer, Mont	46	08	107	27		x	
319	Fort Bridger, Wyo	41	23	110	24		09:51	Multiple echoes.
320	Ola, Idaho	44	12	116	15		09:47	Faint then loud sound.
321	Cedarville, Calif	41	51	120	07	x		
322	Ft. Bidwell, Calif	42	00	120	00	x		
323	Fort Hall, Idaho	43	02	112	26	x		
324	Yelland Field, Ely, Nev	39	17	114	52	x		
325	Auburn, Calif	38	57	121	04	x		
326	Eureka, Nev	39	16	116	00	x		
327	Oakley, Idaho	42	14	113	54	x		
328	Salmon, Idaho	45	11	113	53	x		
329	San Francisco, Calif					x		
330	Crescent City, Calif	41	44	124	12	x		
331	Brady, Mont	42	02	111	21	x		

TABLE X.—*Aural reports of explosion, Test 1, Naval Proving Ground, Arco, Idaho, 9:30 a. m., MWT, 29 August 1945*—Con.

No.	Observation point	Latitude		Longitude		Not heard	Heard time MWT	Remarks
		°	′	°	′			
332	Goldbutte, Mont	48	58	111	23	x		
333	Dunkirk, Mont	48	39	111	31	x		
334	Crater Lake National Park, Oreg					x		
335	Fort Collins, Colo	40	35	105	04	x		
336	Glacier National Park, Mont					x		
337	Lakeview, Oreg	42	33	119	39	x		
338	Roland, Idaho	47	21	115	40	x		
339	Sexton Summit, Oreg	42	36	123	22	x		
340	Moose, Wyo	43	49	110	41	x		
341	Trona, Calif	35	45	117	30	x		
342	Elk Valley, Calif	42	00	123	42	x		
343	Telegraph Creek, Mont	47	47	107	38	x		
344	Oceanside, Calif	33	14	117	25	x		
345	Lamar, Colo	38	04	102	37	x		
346	Prospect, Oreg	42	47	122	29	x		
347	Independence, Calif	37	00	118	00	x		
348	Gold Creek, Nev	41	45	115	40	x		
349	Hamilton, Mont	46	15	114	09	x		
350	Grouse, Idaho	43	42	113	37	x		
351	Glenns Ferry, Idaho	42	57	115	19	x		
352	Challis National Forest, Idaho	44	36	114	28	x		
353	Fence Meadow Lookout, Calif	37	00	119	10	x		
354	Tip Top, Wash	47	37	120	35	x		
355	Hoodsport, Wash	47	25	123	10	x		
356	Grace, Idaho	42	35	111	44	x		
357	Ingomar, Mont	46	13	107	19	x		
358	Barton Flat, Idaho	44	03	113	48	x		
359	Cloverdale, Oreg	45	11	123	53	x		
360	Culbertson, Mont	48	08	104	32	x		
361	Tonopah, Nev	38	04	117	06	x		
362	Grand View, Idaho	42	59	116	06	x		
363	Rosalia, Wash	47	14	117	21	x		
364	Sherman Branch Experiment Station, Oreg.	45	27	120	42	x		
365	Langden, N. Dak	48	46	98	20	x		
366	Ochora Forest, Calif	40	20	120	20	x		
367	Mackey Ranger Station, Idaho	43	55	113	36	x		
368	Redding, Calif	40	42	122	24	x		
369	Cajon, Calif	34	20	117	31	x		
370	Lockheed Air Terminal, Calif	34	12	118	22	x		
371	Death Valley, Calif	36	00	116	00	x		
372	Pomona, Calif	34	04	117	44	x		
373	Santa Clara, Calif	37	20	121	57	x		
374	Bishop, Calif	37	22	118	25	x		
375	Tehachapi, Calif	35	08	118	27	x		
376	Westhaven, Calif					x		
377	Middlewater, Calif	35	33	119	52	x		
378	Coachella, Calif	33	15	116	10	x		
379	Long Beach, Calif	33	47	118	10	x		
380	Santa Rosa, Calif	38	26	122	42	x		
381	Mount Shasta, Calif	41	17	122	16	x		
382	do	41	18	122	18	x		
383	Blue Canyon, Calif	39	16	120	45	x		
384	Pasadena, Calif	34	03	118	10	x		
385	Tahoe, Calif	39	10	120	10	x		
386	Oakland, Calif	37	43	122	13	x		
387	Sandberg, Calif	34	45	118	44	x		
388	Arlight, Calif	34	33	120	36	x		
389	Newhall, Calif	34	24	118	32	x		
390	Goleta, Calif	34	25	119	48	x		
391	Fresno, Calif	36	43	119	49	x		
392	Lodi, Calif	38	07	121	17	x		
393	Los Angeles, Calif	34	03	118	15	x		
394	Red Bluff, Calif	40	09	122	15	x		
395	Los Angeles, Calif	34	03	118	32	x		
396	Beaumont, Calif	33	56	116	56	x		
397	Palomar, Calif	33	21	116	51	x		
398	March Field, Calif	33	53	117	15	x		
399	San Diego, Calif	32	43	117	10	x		
400	Needles, Calif	34	47	114	38	x		
401	El Centro, Calif	32	49	115	39	x		
402	Donner Summit Pass, Calif	39	19	120	20	x		
403	Sacramento, Calif	38	31	121	30	x		

TABLE X.—*Aural reports of explosion, Test 1, Naval Proving Ground, Arco, Idaho, 9:30 a. m., MWT, 29 August 1945*—Con.

No.	Observation point	Latitude °	Latitude ′	Longitude °	Longitude ′	Not heard	Heard time MWT	Remarks
404	Eureka, Calif	40	48	124	11	x		
405	Oakland, Calif	37	44	122	12	x		
406	Imperial, Calif	32	51	115	34	x		
407	Bakersfield, Calif	35	25	119	03	x		
408	Lake Arrowhead, Calif	34	15	117	11	x		
409	Baker, Calif	35	20	116	05	x		
410	Mojave, Calif	34	36	118	11	x		
411	San Bruno, Calif	37	37	122	23	x		
412	Williams, Calif	39	06	122	09	x		
413	Mount Hamilton, Calif	37	20	121	40	x		
414	Santa Cruz, Calif	37	05	122	06	x		
415	Ukiah, Calif	39	08	123	12	x		
416	King City, Calif	36	13	121	08	x		
417	Santa Maria, Calif	34	54	120	27	x		
418	Yosemite National Park, Calif	37	45	119	49	x		
419	Rice, Calif	34	09	115	07	x		
420	Brookings, Oreg					x		
421	Baker, Oreg	44	46	117	51	x		
422	Vale, Oreg	43	58	117	15	x		
423	Burns, Oreg	43	35	119	08	x		
424	Canyon City, Oreg	44	23	118	58	x		
425	Pendleton, Oreg	45	41	118	51	x		
426	Prineville, Oreg	44	19	120	52	x		
427	Springfield, Oreg	44	06	122	41	x		
428	McMinnville, Oreg	45	12	123	12	x		
429	Forest Grove, Oreg	45	31	123	05	x		
430	Salem, Oreg	44	55	123	00	x		
431	Dallesport, Oreg	45	37	121	09	x		
432	Medford, Oreg	42	23	122	52	x		
433	Enterprise, Oreg	45	24	117	19	x		
434	Baker, Oreg	44	52	117	51	x		
435	do	44	52	117	51	x		
436	Crescent, Oreg	43	28	121	42	x		
437	Siskiyou Summit, Oreg	42	05	122	34	x		
438	Portland, Oreg	45	36	122	36	x		
439	Eugene, Oreg	44	07	123	13	x		
440	Mount Hebron, Calif	41	47	122	10	x		
441	Shasta County, Calif	40	44	122	30	x		
442	Portland, Oreg	45	33	122	34	x		
443	Roseburg, Oreg	43	13	123	20	x		
444	Bellingham, Wash	48	48	122	32	x		
445	Diablo Dam, Wash	48	43	121	08	x		
446	Easton, Wash	47	15	121	11	x		
447	Yakima, Wash	46	34	120	32	x		
448	Ephrata, Wash	47	18	119	31	x		
449	Prosser, Wash	46	20	119	50	x		
450	Newport, Wash					x		
451	Stehekin, Wash	48	20	120	42	x		
452	Walla Walla, Wash	46	06	118	17	x		
453	Spokane, Wash	47	40	117	20	x		
454	Goldendale, Wash	45	40	120	50	x		
455	Pullman, Wash	46	45	117	15	x		
456	Stevenson, Wash	45	43	121	50	x		
457	Naches, Wash	46	20	120	19	x		
458	Ellensburg, Wash	47	01	120	29	x		
459	Snoqualmie, Wash	47	31	121	15	x		
460	Kelso, Wash	46	08	122	55	x		
461	Ariel, Wash	46	00	122	30	x		
462	Coulee Dam, Wash	47	58	118	59	x		
463	Olympia, Wash	46	58	122	54	x		
464	Forks, Wash	47	55	124	23	x		
465	Omak, Wash	48	26	119	32	x		
466	Alder, Wash	46	50	122	16	x		
467	Colville, Wash	48	32	117	52	x		
468	Winlock, Wash	46	29	122	48	x		
469	North Head, Wash	46	18	124	05	x		
470	Cle Elum, Wash	47	15	120	50	x		
471	Ellensburg, Wash	47	02	120	31	x		
472	Coeur d'Alene, Idaho	47	46	116	49	x		
473	Idaho City, Idaho	43	50	115	50	x		
474	Grangeville, Idaho	46	00	116	00	x		
475	American Falls, Idaho	42	46	112	52	x		
476	Driggs, Idaho	43	43	111	07	x		

TABLE X.—*Aural reports of explosion, Test 1, Naval Proving Ground, Arco, Idaho, 9:30 a. m., MWT, 29 August 1945*—Con.

No.	Observation point	Latitude °	Latitude ′	Longitude °	Longitude ′	Not heard	Heard time MWT	Remarks
477	Gooding, Idaho	42	55	114	47	x		
478	Island Park Dam, Idaho	44	26	111	24	x		
479	Gray, Idaho	43	04	111	22	x		
480	Porthill, Idaho	49	00	116	30	x		
481	Sugar, Idaho	43	52	111	46	x		
482	Caldwell, Idaho	43	39	116	41	x		
483	Rigby, Idaho	43	38	111	46	x		
484	Ashton, Idaho	44	05	111	27	x		
485	Irwin, Idaho	43	24	111	18	x		
486	Winchester, Idaho	46	14	116	36	x		
487	Blackfoot, Idaho	43	11	112	21	x		
488	May, Idaho	44	36	113	55	x		
489	Moscow, Idaho	46	44	117	00	x		
490	Malad City, Idaho	42	10	112	15	x		
491	Strevell, Idaho	42	01	113	13	x		
492	Preston, Idaho	42	05	111	52	x		
493	Mullan, Idaho	47	27	115	40	x		
494	Cottonwood, Idaho	46	03	116	21	x		
495	Payette, Idaho	44	05	116	56	x		
496	Boise, Idaho	43	34	116	13	x		
497	Challis, Idaho	44	30	114	14	x		
498	Hailey, Idaho	43	31	114	19	x		
499	Obsidian, Idaho	43	57	114	49	x		
500	Burley, Idaho	42	32	113	43	x		
501	Reno, Nev	39	30	119	47	x		
502	Fallon, Nev	39	25	118	43	x		
503	Beatty, Nev	36	55	116	45	x		
504	Humboldt Field, Nev	40	02	118	11	x		
505	Reno, Nev	39	30	119	47	x		
506	Battle Mountain, Nev	40	32	116	52	x		
507	Tonopah, Nev	38	26	117	12	x		
508	Owyhee, Nev	41	58	116	06	x		
509	Pioche, Nev	37	55	114	30	x		
510	Clayton, N. Mex	36	27	103	09	x		
511	Prescott, Ariz	34	27	112	24	x		
512	Nixon, Nev	39	48	119	21	x		
513	Payson, Ariz	34	00	111	00	x		
514	Gila Bend, Ariz	32	18	112	45	x		
515	Prescott, Ariz	34	39	112	26	x		
516	Tucson, Ariz	32	07	110	55	x		
517	St. Johns, Ariz	34	31	109	21	x		
518	Cochise, Ariz	32	02	109	55	x		
519	Holbrook, Ariz	34	49	109	52	x		
520	Flagstaff, Ariz	35	30	111	50	x		
521	Globe, Ariz	33	24	110	47	x		
522	Acomite, N. Mex	35	03	107	45	x		
523	Moriarty, N. Mex	35	05	106	00	x		
524	Engle, N. Mex	33	11	106	59	x		
525	Tucumcari, N. Mex	35	11	103	36	x		
526	Clearcreek, Utah	39	38	111	09	x		
527	Ogden, Utah	41	12	112	01	x		
528	do	41	12	112	01	x		
529	Fairfield, Utah	40	20	112	03	x		
530	Woodruff, Utah	41	31	111	09	x		
531	Milford, Utah	38	26	113	00	x		
532	Delta, Utah	39	23	112	31	x		
533	Kanab, Utah	37	03	112	32	x		
534	Fillmore, Utah	38	58	112	20	x		
535	Roosevelt, Utah	40	18	109	59	x		
536	Willard, Utah	41	30	112	00	x		
537	Salt Lake City, Utah	40	47	111	58	x		
538	Coalville, Utah	40	55	111	24	x		
539	Deseret, Utah	39	17	112	39	x		
540	Fort Duchesne, Utah	40	18	109	51	x		
541	Grantsville, Utah	40	36	112	28	x		
542	Park Valley, Utah	41	50	113	20	x		
543	Lucin, Utah	41	22	113	50	x		
544	Brigham City, Utah	41	28	112	16	x		
545	Bryce Canyon, Utah	37	38	112	10	x		
546	Bluff, Utah	37	18	109	33	x		
547	Moab, Utah	38	34	109	33	x		
548	Modena, Utah	37	41	113	40	x		
549	Blanding, Utah	37	38	109	28	x		

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No.	Observation point	Latitude °	Latitude ′	Longitude °	Longitude ′	Not heard	Heard time MWT	Remarks
550	Salt Lake City, Utah	40	46	111	54	x		
551	Forks, Mont	48	46	107	26	x		
552	Glasgow, Mont	48	11	106	38	x		
553	Cut Bank, Mont	48	36	112	22	x		
554	Westby, Mont	48	53	104	03	x		
555	Butte, Mont	45	58	112	30	x		
556	Barber, Mont	46	18	109	23	x		
557	Mildred, Mont	46	41	104	56	x		
558	Wyola, Mont	45	08	107	24	x		
559	Plains, Mont	47	20	114	50	x		
560	Whitehall, Mont	45	48	112	16	x		
561	Billings, Mont	45	48	108	32	x		
562	Bozeman, Mont	45	40	111	00	x		
563	Jordan, Mont	47	30	106	50	x		
564	Ekalaka, Mont	45	53	104	34	x		
565	Mystic Lake, Mont	45	14	109	45	x		
566	Lewistown, Mont	47	03	109	27	x		
567	Miles City, Mont	46	26	105	52	x		
568	Helena, Mont	46	36	112	00	x		
569	Drummond, Mont	46	38	113	11	x		
570	Lame Deer, Mont	45	38	106	40	x		
571	Stevensville, Mont	46	18	114	36	x		
572	Missoula, Mont	45	55	114	05	x		
573	Wisdom, Mont	45	40	113	30	x		
574	Great Falls, Mont	47	30	111	21	x		
575	Darby, Mont	46	03	114	11	x		
576	Harlem, Mont	48	42	108	47	x		
577	Havre, Mont	48	34	109	40	x		
578	Browning, Mont	48	34	113	01	x		
579	Kalispell, Mont	48	10	114	25	x		
580	White Sulphur Springs, Mont	46	32	110	53	x		
581	Haugan, Mont	47	22	115	24	x		
582	Lonepine, Mont	47	43	114	39	x		
583	Lima, Mont	44	39	112	36	x		
584	Fairview, Mont	47	51	104	01	x		
585	Livingston, Mont	45	40	110	32	x		
586	Dillon, Mont	45	15	112	33	x		
587	Libby, Mont	48	24	115	32	x		
588	Augusta, Mont	47	36	112	47	x		
589	Frazer, Mont	48	04	106	02	x		
590	Stanford, Mont	47	09	110	12	x		
591	Crow Agency, Mont	45	35	107	20	x		
592	Helena, Mont	47	30	110	00	x		
593	Winnett, Mont	47	00	108	20	x		
584	Lusk, Wyo	42	44	104	28	x		
595	Sinclair, Wyo	41	48	107	03	x		
596	Laramie, Wyo	41	18	105	40	x		
597	Wardwell Field, Wyo	42	55	106	20	x		
598	La Bange, Wyo	42	15	110	20	x		
599	Lander, Wyo	42	50	108	45	x		
600	Cheyenne, Wyo	41	09	104	49	x		
601	Douglas, Wyo	42	44	105	22	x		
602	Big Piney, Wyo	42	32	110	03	x		
603	Rock Springs, Wyo	41	36	109	06	x		
604	Sheridan, Wyo	44	46	106	58	x		
605	Pueblo, Colo	38	14	104	38	x		
606	La Junta, Colo	38	03	103	57	x		
607	Leadville, Colo	39	15	106	18	x		
608	Mesa County, Colo	39	06	108	44	x		
609	Stapleton Field, Colo	39	46	104	53	x		
610	Denver, Colo	39	45	105	00	x		
611	Trinidad, Colo	37	15	104	20	x		
612	Akron, Colo	40	10	103	10	x		
613	Estes Park, Colo	40	25	105	45	x		
614	Alamosa, Colo	37	26	105	51	x		
615	Overton, Nebr	40	44	99	26	x		
616	Hayes Center, Nebr	40	31	100	58	x		
617	Lincoln, Nebr	40	52	96	46	x		
618	North Platte, Nebr	41	08	100	45	x		
619	Sidney, Nebr	41	08	102	59	x		
620	Chadron, Nebr	42	50	103	05	x		
621	Scotts Bluff, Nebr	41	52	103	36	x		
622	North Platte, Nebr	41	08	100	42	x		

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No.	Observation point	Latitude		Longitude		Not heard	Heard time MWT	Remarks
		°	′	°	′			
623	Big Springs, Nebr	41	05	102	07	x		
624	Grand Island, Nebr	40	59	98	18	x		
625	Pierre, S. Dak	44	23	100	17	x		
526	Philip, S. Dak	44	03	101	36	x		
627	Huron, S. Dak	44	21	98	14	x		
688	Rapid City, S. Dak	44	09	103	06	x		
629	Velva, N. Dak	48	05	100	55	x		
630	Linton, N. Dak	46	16	100	14	x		
631	Kensal, N. Dak	47	15	98	52	x		
632	Jamestown, N. Dak	46	55	98	41	x		
633	Amidon, N. Dak	46	29	103	30	x		
634	Foxholm, N. Dak	48	30	101	33	x		
635	Petersburg, N. Dak	48	00	98	00	x		
636	Rugby, N. Dak	48	30	99	00	x		
637	Devils Lake, N. Dak	48	07	98	52	x		
638	Ashley, N. Dak	46	02	99	21	x		
639	Minot, N. Dak	48	16	101	17	x		
640	Ellendale, N. Dak	45	58	98	38	x		
641	Bismarck, N. Dak	46	47	100	46	x		
642	Grand Forks, N. Dak	47	56	97	05	x		
643	Fargo, N. Dak	46	54	96	48	x		
644	Pembina, N. Dak	48	55	97	10	x		
645	Golva, N. Dak	46	40	103	57	x		
646	Steele, N. Dak	46	51	99	56	x		
647	Valley City, N. Dak	46	56	98	00	x		
648	Garden City, Kans	37	58	100	59	x		
649	Goodland, Kans	39	21	101	40	x		
650	Dodge City, Kans	37	46	99	58	x		
651	Twin Peaks, Calif	34	15	117	30	x		
632	Congress, Ariz	34	10	112	44	x		
653	Chinle, Ariz	36	09	109	32	x		
654	Skull Valley, Ariz	34	30	112	40	x		
655	Fredonia, Ariz	36	57	112	32	x		
656	Holbrook, Ariz	34	49	109	52	x		
657	Navajo, Ariz	36	40	110	31	x		
658	Coolidge, Ariz	33	00	110	32	x		
659	Flagstaff, Ariz	35	16	111	45	x		
660	Grand Canyon, Ariz	36	03	112	08	x		
661	Alpine, Ariz	33	50	109	08	x		
662	Ajo, Ariz	31	55	112	50	x		
663	Jerome, Ariz	34	50	112	10	x		
664	Ajo, Ariz	32	22	112	51	x		
665	Payson, Ariz	34	16	111	28	x		
666	Nogales, Ariz	31	16	110	59	x		
667	Benson, Ariz	31	45	110	17	x		
668	Kingman, Ariz	35	10	114	05	x		
669	Silver Lake, Ariz	34	30	110	05	x		
670	Brokeoff Mt. Calif	40	27	121	34	x		
671	Canyon City, Oreg	44	25	119	00	x		
672	Chico, Calif	39	42	121	49	x		
673	Mineral, Calif	40	21	121	34	x		
674	Zion National Park, Utah	37	15	112	59	x		
675	Las Vegas, Nev	36	16	115	38	x		
576	Sacramento, Calif	38	35	121	30	x		
677	Adaven, Nev	38	06	115	30	x		
678	Los Angeles, Calif	33	56	118	23	x		
679	Mount Hood, Oreg	45	20	121	43	x		
680	Raiwee, Calif	36	22	118	00	x		
681	Three Creek, Idaho	42	03	115	10	x		
682	St. Ignatius, Mont	47	18	114	05	x		
683	Badger, Calif	36	30	118	00	x		
684	Juntura, Oreg	43	45	118	05	x		
685	Bitterroot National Forest	45	50	114	40	x		
686	do	45	35	114	50	x		
687	Kaycee, Wyo	43	40	106	39	x		
688	Mt. Montgomery, Nev	38	00	118	16	x		
689	Fish Lake, Utah	38	40	111	50	x		
690	Rapid City, S. Dak., Seismological Station.	44	46	103	12	x		
691	Seattle, Wash	47	30	122	15	x		
692	Lester, Wash	47	17	121	20	x		
693	Broadus, Mont	45	26	105	25	x		
694	Austin, Nev	39	29	117	02	x		

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No.	Observation point	Latitude °	Latitude ′	Longitude °	Longitude ′	Not heard	Heard time MWT	Remarks
695	Riggins, Idaho	45	26	116	19	x		
596	Springerville, Ariz	34	07	109	34	x		
697	Angela, Mont	46	47	106	08	x		
698	Portland, Oreg	46	10	122	55	x		
699	Pierce, Idaho	46	29	115	48	x		
700	Anatone, Wash	46	00	117	00	x		
701	Bonanza, Oreg	42	17	121	07	x		
702	Rock Island, Wash					x		
703	Salt Lake City, Utah	40	46	111	57	x		
704	do	40	46	111	57	x		
705	Flag Mountain, S. Dak	44	04	103	49	x		
706	Douglas, Ariz	31	20	109	30	x		
707	Oro Blanco, Ariz	31	30	111	15	x		
708	Elko, Nev	40	55	115	45	x		
709	Anton Chico, N. Mex	30	08	105	05	x		
710	El Morro, N. Mex	35	01	108	24	x		
711	Las Vegas, N. Mex					x		
712	Santa Fe, N. Mex	36	38	106	06	x		
713	Albuquerque, N. Mex	35	03	106	37	x		
714	Carrizozo, N. Mex	45	00	105	00	x		
715	Guymon, Okla	36	40	101	30	x		
716	Mogollon, N. Mex	33	24	108	48	x		
717	Raton, N. Mex	36	45	104	30	x		
718	Des Moines, N. Mex	36	46	103	50	x		
719	Tucumcari, N. Mex	35	12	103	41	x		
720	Fort Wingate, N. Mex	35	00	108	30	x		
721	Aztec, N. Mex	36	48	108	00	x		
722	Grants, N. Mex					x		
723	Tyrone, M. Nex	32	35	108	26	x		
724	Santa Fe, N. Mex	33	40	105	55	x		
725	Jensen, Utah	40	27	109	20	x		
726	Paso Robles, Calif	35	36	120	39	x		
727	Los Angeles, Calif	34	37	118	05	x		
728	Bunker Hill, Calif	39	02	122	22	x		
729	Hanksville, Utah	38	23	110	47	x		
730	Conrad, Mont	48	10	111	58	x		
731	Mesa Verde, Colo	37	12	108	30	x		
732	Paradise Valley, Nev	41	29	117	31	x		
733	Tatoosh Island, Wash	48	23	124	44	x		
734	Odell, Mont	45	35	113	15	x		
735	Dillon, Mont	45	15	112	40	x		
736	do	45	15	112	40	x		
737	Moose Creek, Idaho	46	08	114	55	x		
738	Ward Mountain, Mont	46	10	114	12	x		
739	Palisade Mountain, Mont	47	20	113	50	x		
740	Cabinet National Forest, Mont	48	00	116	00	x		
741	Pierce, Idaho	46	50	116	00	x		
742	Coeur D'Alene National Forest	47	43	116	29	x		
743	Coeur d'Alene, Idaho	47	43	116	29	x		
744	Mullen, Idaho	47	28	115	46	x		
745	Wallace, Idaho	47	34	115	50	x		
746	Coeur d'Alene, Idaho	47	41	116	40	x		
747	Mount Coeur d'Alene, Idaho	47	15	116	40	x		
748	Quartz Mountain, Wash	48	30	119	40	x		
749	Colville National Forest, Wash	48	55	118	23	x		
750	Cliff Ridge Lookout, Wash	48	25	117	15	x		
751	Red Lodge, Mont	45	20	109	20	x		
752	Ashland, Mont	45	45	106	15	x		
753	Parker, Ariz	34	09	114	17	x		
754	Camp Crook, S. Dak	45	32	103	59	x		
755	Grassy Mount Lookout, Mont	46	02	113	00	x		
756	Whitehall Ranger, Mont	49	00	112	08	x		
757	Livingston, Mont	45	40	110	32	x		
758	Metaline Falls, Wash	48	50	117	20	x		
759	Hall Mount Lookout, Idaho	48	45	116	15	x		
760	Sand Point, Idaho	48	20	116	30	x		
761	Troy Ranger Stn., Mont	48	30	115	53	x		
762	Libby, Mont	48	03	115	18	x		
763	do	48	24	115	32	x		
764	Slide Rock Mount Lookout, Mont	46	35	115	33	x		
765	Lolo, Mont	46	45	114	05	a		

a=9:50 Distinct explosion.

TABLE X.—*Aural reports of explosion, Test 1, Naval Proving Ground, Arco, Idaho, 9:30 a. m., MWT, 29 August 1945*—Con.

No.	Observation point	Latitude °	Latitude ′	Longitude °	Longitude ′	Not heard	Heard time MWT	Remarks
766	Seeley Lake, Mont	47	13	113	31	x		
767	Superior, Mont	47	10	114	55	x		
768	Fenn Ranger Station, Idaho	46	06	115	30	x		
769	Fish Creek Lookout, Mont	48	20	111	20	b		
770	Coolwater Lookout, Mont	48	30	110	40	c		
771	Dixie, Idaho	45	32	115	27	d		
772	Daggett, Calif	34	52	116	47	x		
773	Williston, N. Dak	48	09	103	35	x		
774	Wallowa, Oreg	45	26	116	37	e		
775	Red Hill, Oreg	45	47	117	02	x		
776	Arlington, Oreg	45	43	120	11	x		
777	Lincoln Co., Wyo	42	30	110	00	f		
778	Panhandle, Tex	36	00	101	00	x		
779	Pine Valley, Utah	37	21	113	24	x		
780	Sonora, Calif	38	00	120	22	x		
781	Grand Junction, Colo	39	04	108	34	x		
782	Council, Idaho	44	45	116	25	x		
783	Happy Camp, Calif	41	50	123	20	x		
784	Springfield, Idaho	43	04	112	41	x		
785	Angeles National Forest	34	22	118	12	x		
786	Newhall, Calif	34	38	118	25	x		
787	Jerome, Idaho	42	43	114	32	x		
788	Modoc National Forest, Calif	41	25	121	28	x		
789	do	41	48	120	19	x		
790	Condon, Oreg	45	14	120	11	x		
791	Baker, Nev	39	00	114	15	x		
792	Flagstaff, Ariz	35	12	111	40	x		
793	Los Padres National Forest, Calif	35	10	120	00	x		
794	Santa Lucia Lookout Forest					x		
795	Big Pine Lookout, Los Padres, Calif					x		
796	Ojai, Calif					x		
797	Olympia National Park					x		
798	Steamboat Springs, Colo					x		
799	Black Hills National Forest, S. Dak	44	18	103	45	x		
800	Sundance, Wyo					x		
801	Idaho Springs, Colo						10:14	
802	Black Hills, S. Dak					x		
803	Mancos, Colo., National Forest					x		
804	Wapiti, Wyo					x		
805	Painter, Wyo					x		
806	Dubois, Wyo	43	33	109	37	x		
807	Sedalia, Colo	39	30	105	00	x		
808	Halsey, Nebr	41	55	100	17	x		
809	Newcastle, Wyo	44	00	104	08	x		
810	Cicero Peak, S. Dak	43	41	103	34	x		
811	Harney Peak, S. Dak	43	52	103	32	x		
812	Bear Mountain Lookout, S. Dak	43	52	103	45	x		
813	Boulder Hill Lookout, S. Dak	43	58	103	24	x		
814	Parker Peak Lookout, S. Dak	43	24	103	41	x		
815	Summit Ridge Lookout, Wyo	43	51	104	03	x		
816	Elk Mountain, Wyo	43	43	104	03	x		
817	Chimney Rock, Dyke, Colo						10:04	Single blast.
818	Roosevelt National Forest, Colo					x		
819	Boulder, Colo					x		
820	Esterbrook, Wyo	42	20	105	20	x		
821	Holmes, Wyo	41	12	106	13	x		
822	Jelm Mountain, Wyo					x		
823	Medicine Bow National Forest, Wyo	41	25	106	32		9:45	
824	Pagosa Springs, Colo					x		
825	Tensleep, Wyo	44	10	107	10	x		
826	Bighorn National Forest	44	44	107	23	x		
827	Buffalo, Wyo	44	14	107	00	x		
828	Safford, Arizona	32	40	109	50	x		
829	Zamora, N. Mex	35	05	106	23	x		
830	Gila National Forest, N. Mex	33	16	108	36	x		
831	Santa Fe National, N. Mex	35	47	106	33	x		
832	Tucson, Ariz	32	25	110	42	x		

b=9:49 Distinct single blast.
c=9:50 Dull thud.
d=9:48 5 blasts.
e=9:51 Faint blast.
f=9:48 2 rumbles.

TABLE X.—*Aural reports of explosions, Test 1, Naval Proving Ground, Arco, Idaho, 9:30 a. m., MWT, 29 August 1945*—Con.

No.	Observation point	Latitude		Longitude		Not heard	Heard time MWT	Remarks
		°	′	°	′			
833	Sunflower, Ariz	33	58	111	27	x		
834	High Rolls, N. Mex	33	00	105	42	x		
835	Winslow, Ariz	34	20	111	00	x		
836	Picuris Peak, N. Mex	36	15	105	39	x		
837	Ogden, Utah	41	13	111	58		9:45	
838	do					x		
839	do						x	
840	Vernal, Utah					x		
841	Big Baldy Lookout, Idaho	44	42	115	12		9:45	3 distinct rumbles.
842	Cascade, Idaho	44	44	115	40		9:45	Low rumble.
843	Arrowrock, Idaho						9:45	3 distinct rumbles.
844	Morehead, Idaho						9:45	Strong earth tremor.
845	Denskin, Idaho						9:45	Do.
846	Idaho City, Idaho						9:45	Rumble.
847	Thorn Creek Butte					x		
848	Scott Mountain, Calif					x		
849	Kemmerer, Wyo	41	48	110	32	x		
850	Willard, Logan, Utah					x		
851	Chink's Peak, Idaho	42	50	112	20	x		
852	Malad City, Idaho					x		
853	Challis National, Idaho					x		
854	Challis, Idaho	44	30	114	14	x		
855	Richfield, Utah					x		
856	Angel Lake, Nev	41	00	115	51	x		
857	Ely, Nev					x		
858	Ephraim, Utah	39	20	111	80	x		
859	Salmon, Idaho					x		
860	do					x		
861	Obsidian, Idaho	43	58	114	45	x		
862	Iron Mountain, Idaho	43	32	115	03		9:41	
863	Hailey, Idaho					x		
864	Bald Mountain, Idaho					x		
865	Teton Pass, Wyo	43	30	110	57		9:39	Single sound.
866	Bishop Mountain Lookout, Idaho	44	20	111	34	x		
867	Jackson, Wyo	43	29	110	46	x		
868	Paradise Valley, Nev					x		
869	Coleville, Calif	38	12	119	26	x		
870	Uinta National, Utah					x		
871	Mill Creek Ranger Station, Utah	40	56	110	44		9:54	2 faint sounds.
872	Grantsville, Utah					x		
873	Chelan National Forest, Wash	48	45	120	04	x		
874	Twisp, Wash					x		
875	Carson, Wash	45	48	122	06		9:59	Sharp report
877	Lake View, Oreg					x		
878	Silver Lake, Oreg	43	20	121	20	x		
879	Mt. Hood Forest Lakes	45	01	121	39	x		
880	Larch Mountain Lookout					x		
881	Olympia National Forest					x		
882	do					x		
883	Trail, Oreg	42	45	123	45		10:46	
884	Jacksonville, Oreg	42	12	123	09		10:25	
885	Snow Camp Lookout, Oreg	42	20	124	10	x		
886	Ship Mountain Lookout, Calif	40	44	123	46	x		
887	Mary's Peak Lookout, Oreg	44	30	123	23	x		
888	Bell Mountain Lookout, Oreg	45	00	123	30	x		
889	Granite Mountain Lookout, Wash					x		
890	Heppner, Oreg	45	06	119	28		10:54	Single blast.
891	Pomeroy, Wash	46	12	117	35	x		
892	Fairview Lookout, Calif	40	30	122	40		10:13	Prolonged rumble.
893	Cinnamon Butte, Oreg					x		
894	Baker, Oreg	44	53	117	20	x		
895	Lane, Oreg					x		
896	Dubois, Idaho	44	14	112	09		9:35	
897	do	44	10	112	13		9:34	4 or 5 rolling sounds.
898	West Yellowstone, Mont	44	39	111	06		9:38:47	By electromagnetic barograph.

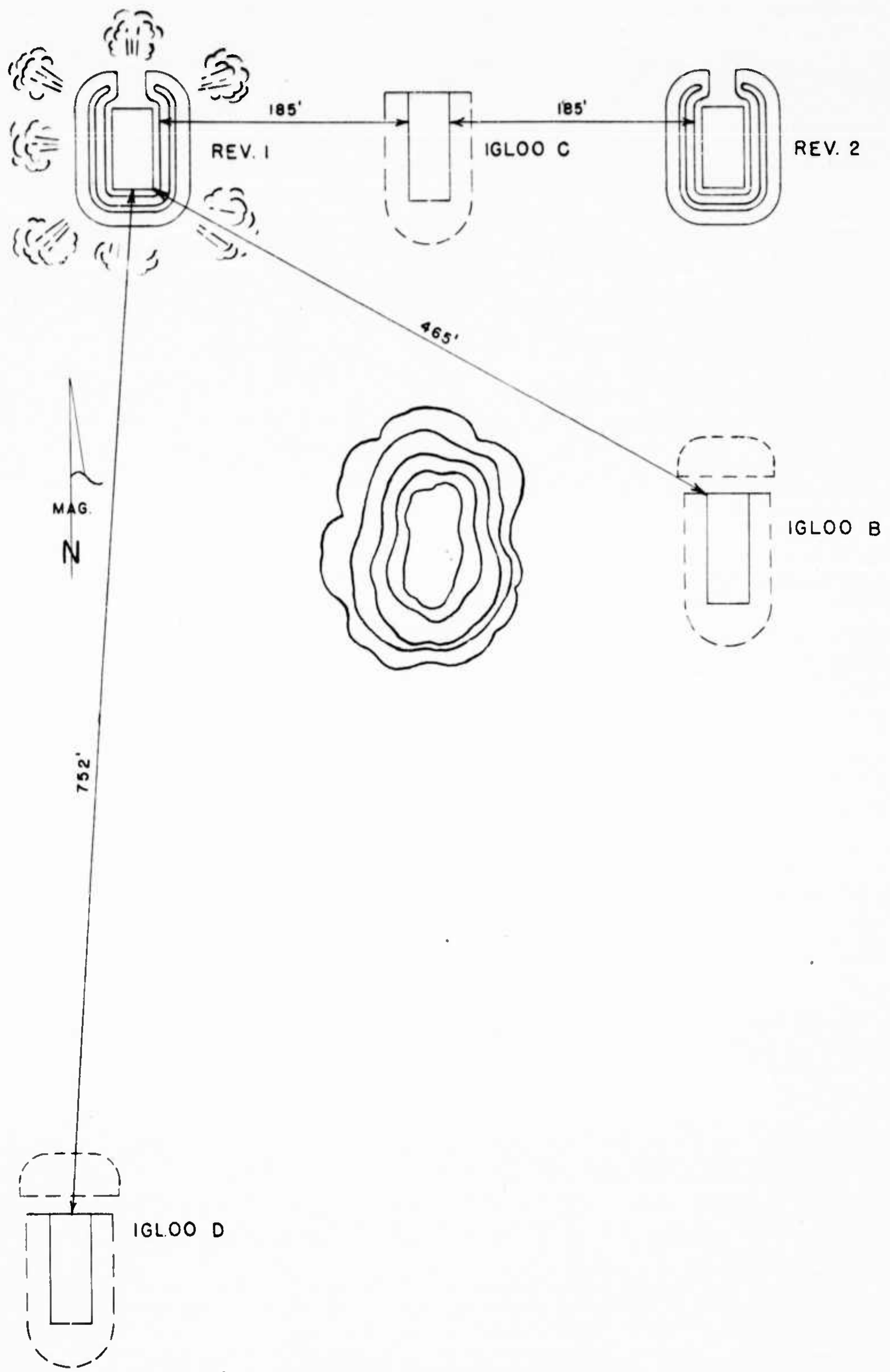


FIGURE 63. Field layout, Test 2

B.—H. E. IGLOO TEST NO. 2—18 OCTOBER 1945

1. General

After Test 1, two earth barricaded, open storage sites (revetments) as shown in figures 6 and 7 were constructed. One of these revetments was located 185′ east of Igloo C and the other 185′ west of Igloo C. The amatol loaded bombs stored in Igloo B during Test 1 were removed therefrom and stored in equal quantities (125,000 net pounds of explosives each) in Revetments 1 and 2. The Navy depth charges loaded with Torpex, which were stored in Igloo D during Test 1, were removed and restored in Igloo B. The doors of Igloo C were repaired and a sand bag barricade was constructed in Igloo C to prevent the doors from hitting the piles of ammunition stored therein, if they should be again blown off in subsequent explosions. This latter precaution was taken to eliminate the possibility of the contents of Igloo C being detonated by doors blown with force into or against the piles of depth charges. A temporary timber and earth door barricade of the Navy type was constructed in front of Igloo B.

2. Purpose

a. To determine if the mass detonation of 125,000 pounds of high explosives stored in an earth barricaded open storage site (Revetment 1) will propagate to a Navy Igloo C, located 185 feet to the side of the site or to another earth barricaded open storage site (Revetment 2) located 185 feet farther beyond the igloo.

b. To determine the severity of the damage done to the target igloos, the open storage site, and their contents.

c. To record data pertaining to air blast pressures, seismic action, crater size, and ground movement.

3. Test layout

This test involved the explosion of 125,000 50/50 Amatol in bombs in Revetment 1 *vs.* target units Army Igloo B, Navy Igloos C and D, and Revetment 2, located as shown in figures 63 and 64. This layout provided a test of the safety of the emergency revetment storage authorized by the ANESB in 1945.

4. Revetment and igloo contents

a. Revetments 1 and 2 were each loaded with two hundred and eight 1100-pound and nine 600-pound bombs, explosive charge 50/50 Amatol, for a total of 125,000 pounds of high explosives. These bombs were stored as shown in figures 65a, 65b, and 65c.

b. Igloos B and C were each loaded with five hundred and forty-one 650-pound Aircraft Depth Bombs, Mark 49, explosive charge 462 pounds of Torpex, for a total of 250,000 pounds of high

FIGURE 64. Revetment 1, Igloo C, and (right) door barricade at Igloo B, prior to Test 2.

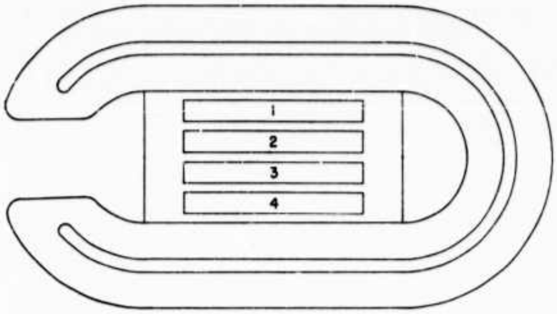


FIGURE 65a. Revetment storage diagram, Test 2.

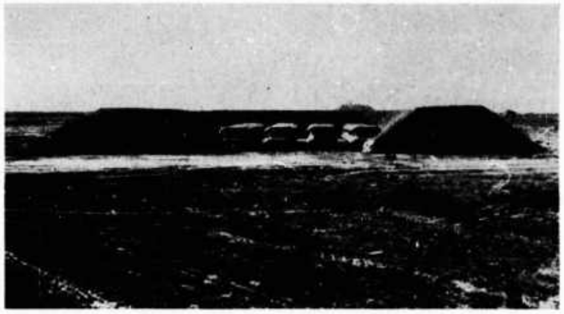


FIGURE 65b. Revetment storage, Test 2.

FIGURE 65c. Revetment storage, Test 2.

explosives. These bombs were stored as shown in figure 16. Igloo D was not loaded.

5. Priming

Approximately one-half of the bombs in stacks 2 and 4 of Revetment 1 were primed by packing knotted primacord surrounded by Composition C–2 into the nose cavity of each bomb as in Test 1. A single primacord lead passed down the side of Stack 2 connecting all primed bombs in that stack and this lead joined a similar lead from Stack 4 at the rear of the revetment. Three Engineer Special electric blasting caps were connected to the two leads and the caps were connected to the firing circuit in parallel.

6. Description of test and summary of results

a. General.—Revetment 1 was exploded at 1440 MWT on 18 October 1945. The explosion of the 125,000 pounds of Amatol in Revetment 1 produced much more visible flame than the igloo explosions and the dense black smoke cloud rose in a mushroom shape with a boiling crest of smoke and red flame above a column of smoke (see fig. 66). There was no propagation of the explosion of Revetment 1 to target Igloos C, B, and D and Revetment 2, all of which suffered little or no damage.

b. Motion picture record.—Motion pictures were obtained which show the explosion of 125,000 pounds of Amatol in Revetment 1 at normal film speed.

c. Air blast pressures.—Air blast pressures were measured by north and west meter lines of paper

FIGURE 66. Explosion, revetment 1.

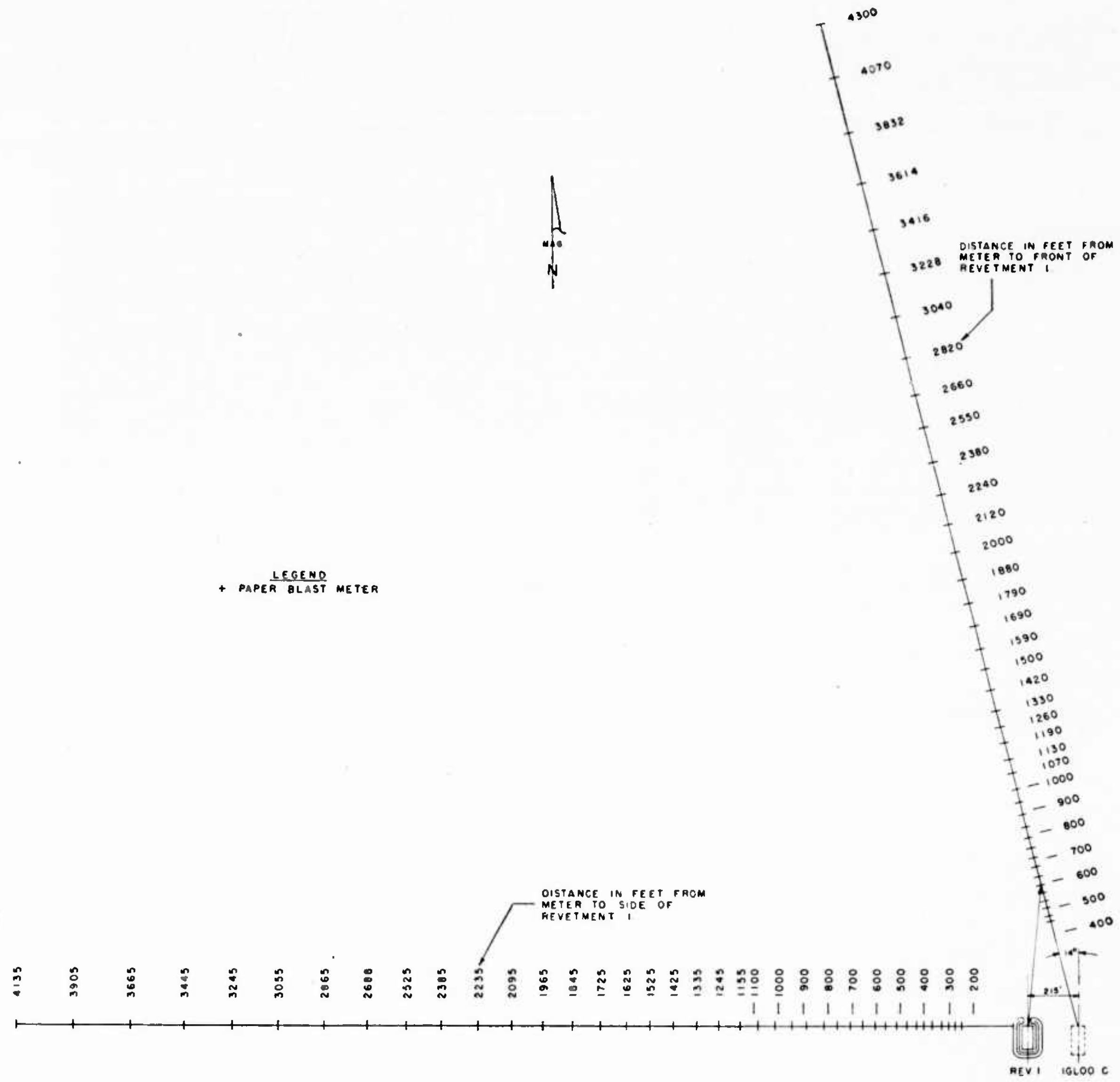


FIGURE 67. Blast meter layout.

blast meters, as shown in figure 67. The pressures recorded are shown in table XI.

d. Crater data.—The explosion of the contents of Revetment 1 produced a crater 82 feet long, 79 feet wide, with an apparent depth of 7.7 feet and an actual depth of 10 feet. Figure 68 shows contours and profiles of the apparent crater along its longitudinal and transverse axes.

e. Ground movement.—Horizontal and vertical displacement readings were taken to the rear and front but not to the sides of the revetment (fig. 69).

f. Effect of blast on target igloos and revetments.

(1) Igloo C received minor damage as a result of the explosion. The doors were blown off, striking the sand-bag barricade inside the door and then falling outside the magazine (see fig. 70), but the contents of the igloo were undisturbed. Igloos B, D, and Revetment 2 were undamaged.

(2) Strain measurements (Ref. 4) were taken by the Bureau of Reclamation, Department of the Interior. Three meters were placed on Igloo C approximately on the transverse center line on the outside of the shell with their axes parallel to the

TABLE XI.—*Test No. 2—18 October 1945—air blast pressures paper meters*

Distance from side or front of Rev. No. 1, in feet	Pressure range in p. s. i.		Remarks	Distance from side or front of Rev. No. 1, in feet	Pressure range in p. s. i.		Remarks
	North line (off front)	West line (off side)			North line (off front)	West line (off side)	
247		12.6	Blown over.	1,330	1.8		
273		12.6	Do.	1,335		1.8	
302		7.7	Do.	1,420	1.2		
330		12.6	Do.	1,425		1.8	
367		7.7	Do.	1,500	1.8		
400		7.7	Do.	1,525		.8	
435		5.8	Do.	1,590	1.2		
457	5.8		Dol	1,625		1.2	
473	5.8		Do.	1,690	1.2		
476		7.7	Do.	1,725		.8	
507	5.8		Do.	1,790	1.2		
516		5.8	Do.	1,845		.8	
533	3.6		Do.	1,880	.8		
560		3.6	Do.	1,965		.8	
568	5.8		Do.	2,000	.8		
598	3.6		Do.	2,095		.8	
605		5.8	Do.	2,120	.8		
631	3.6		Do.	2,235		.8	
653		5.8	Do.	2,240	.4		
671	3.6		Do.	2,380	.6		
706		3.6	Do.	2,385		.4	
710	3.6		Do.	2,525		.8	
751	3.6		Do.	2,550	.8		
760		3.6	Do.	2,660	.6		
795	2.7			2,685		.6	
815		5.8	Do.	2,820	.6		
842	3.6		Do.	2,865		0	Blown over
885		2.7		3,040	.4		
894	2.7			3,055		0	
945		2.7	Do.	3,228	.6		
946	2.7			3,245		0	
1,000	2.7			3,416	0		
1,015		2.7		3,445		0	
1,070	2.7			3,614	0		
1,085		2.7		3,665		0	
1,130	1.8			3,832	0		
1,155		2.7		3,905		0	
1,190	1.8			4,070	0		
1,245		1.8		4,135		0	
1,260	1.8			4,300	.4		

transverse center line (fig. 71). The stresses which developed at the three locations are shown on the vertical scale, figure 72a, with the time after detonation shown on the horizontal scale. The time is considered to be accurate to 0.01 second, but some inaccuracy may be present in the stress scale because the exact modulus of elasticity of the concrete is not known. The strain was converted into stress by using an assumed value for the modulus of elasticity of 4,000,000 p. s. i.

Interpretation of the stress-time diagram in terms of the structural behavior of the igloo must be highly speculative because of the limited number of measurements and because supplemental data which would be helpful in the interpretation are not available. Nevertheless, it seems worth while to discuss some of the results obtained.

It is probable that the very small initial humps at 0.08 second after the detonation represent deformation of the shell due to the initial ground wave. The distance involved is too small for an accurate determination of velocity, but taking the distance as 197 feet and the time as 0.078 second, the indicated velocity is 2,520 feet per second. The stresses produced by this initial ground wave were small, of the order of 50 p. s. i. It will be noted that Meter 1 shows slight tension and Meter 3 shows slight compression, corresponding o the raking which would be produced by an acceleration directed away from the blast. Following these initial distortions, further effects of ground movement are obscured by the much greater effects of variations in air pressure.

The time of advent of the positive or compressional air wave is about 0.09 second, which

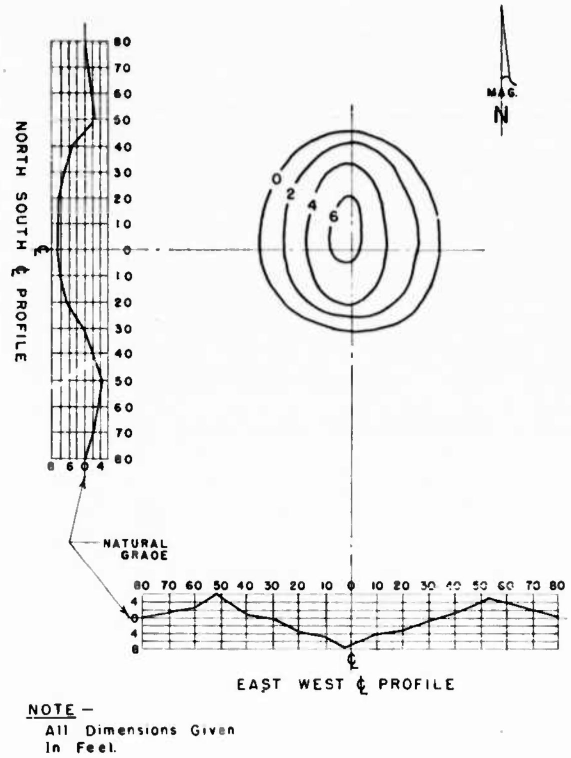


FIGURE 68. Crater plan and profiles, Revetment 1, Test 2

indicates a velocity of about 2,200 feet per second. This wave produced an added external load which put the entire structure into compression for about 0.03 second, the magnitude of the compression being 900 p. s. i. at Meter 1 (nearest the blast), 700 p. s. i. at Meter 2, and 350 p. s. i. at Meter 3.

The compression wave was followed immediately by a period of reduced pressure, constituting in effect an added internal load sufficient to put the entire shell into tension and to cause local failures of the concrete. Meter 2, located over the thin top section of the shell, indicates that the concrete failed in tension when the stress reached 800 p. s. i. Examination of the igloo prior to the blast had shown the presence of a minor longitudinal crown crack on the inside surface only. The outside surface had been examined carefully at the location of Meter 2 and this location was then free from cracks. Examination of the outside surface after the blast disclosed a crack 0.04 inch wide passing between the brackets of the strain meter (fig. 72b). The limiting range of these meters is 0.01 inch, so the large crack explains the meter failure. Concrete at Meter 1 reached a maximum tension of 900 p. s. i. and then came down to a somewhat lower level, while the peak tension reached at Meter 3 was 600 p. s. i.

There seems to be two possible explanations for the cyclic irregularities shown by Meters 1 and 3 during the tension phase. The first is that some observers have reported experimental evidence showing that the suction wave which follows an explosion is made up of a succession of shock phases; the other is that as the suction wave builds up, the tension in the concrete is periodically relieved by the formation of cracks. It is of interest to note that the rapid rate at which tension was developing at Meter 3 reduced abruptly as soon as the occurrence of the crack at Meter 2 afforded relief of the tension. This circumstance favors the second explanation. On the other hand, the pronounced similarity of the variations shown by Meter 1 and 3 suggests that the air pressure varied periodically. It may be then that both causes of these variations were operative.

It is likely that a pressure differential between the inside and outside sufficient to produce the measured tension would also be suffieient to lift the entire arch off its foundation.

Some question has been raised as to whether the residual tensions shown at the end of the record actually exist or if they might be due to a zero drift in the recording instrument. Although the question cannot be answered positively, no reason has been found to question the accuracy of the record, so it is presumed that the final tensions are the result of permanent deformation of the structure.

g. Damage to barracks.—Not recorded.

h. Missile data.—Not recorded.

i. Seismological data (Ref. 7).—The seismological data obtained during this test are given in table XII.

TABLE XII.—*Accelerations and displacements*

Distance from Revetment 1, in feet	Explosives weight in lbs.	Wave period secs.	Maximum displacement, cm.	Maximum acceleration, cm/sec.²	Remarks
2,840	125,000	0.19	0.0033	4.0	Rock.
2,840	125,000	.16	.008	12.5	Overburden.
5,600	125,000	.27	.0045	2.4	Do.
9,200	125,000	.37	.0015	.42	Do.

j. Meteorological data.—Not recorded.

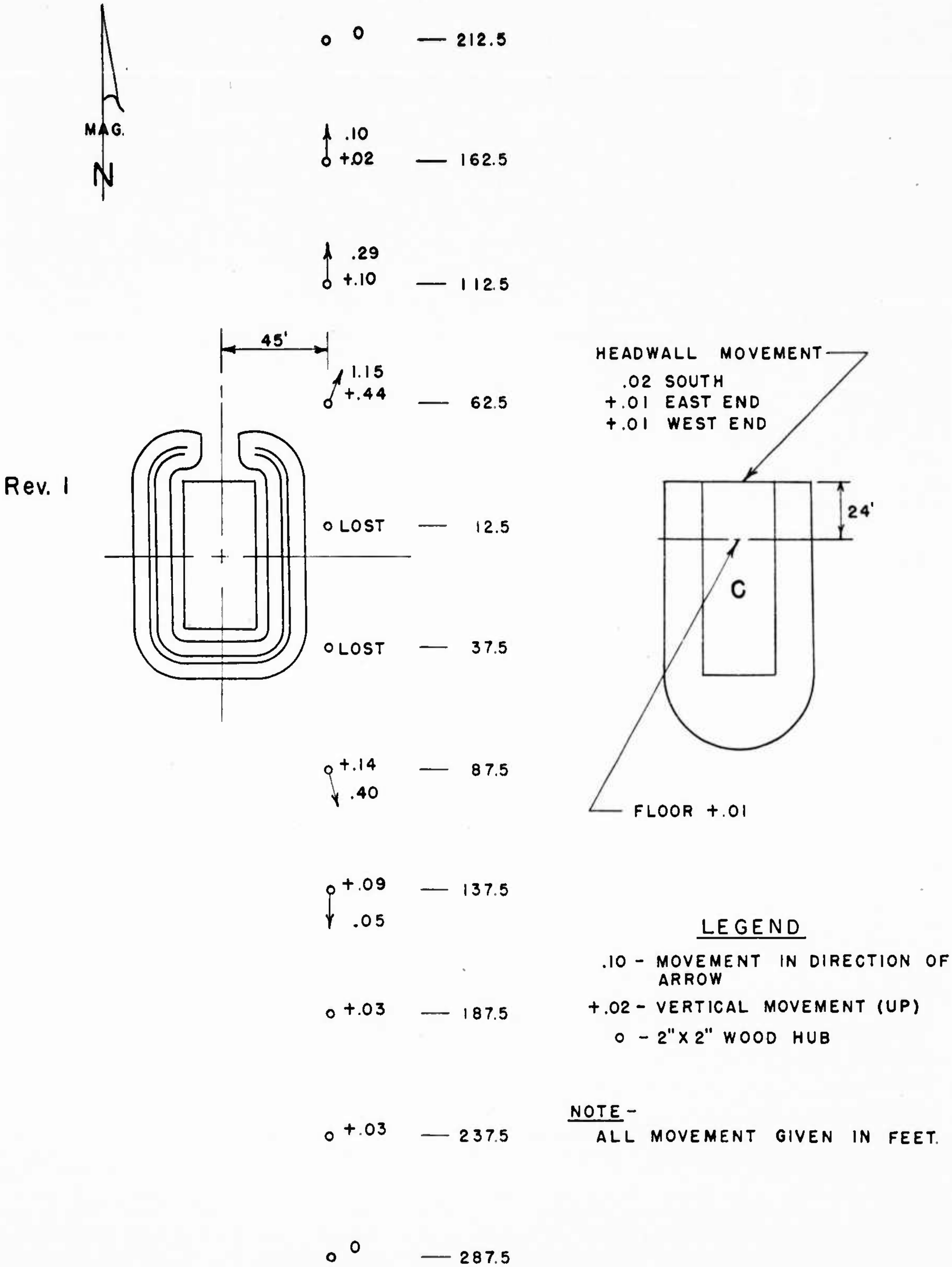


FIGURE 69. Permanent horizontal and vertical earth displacement, Test 2.

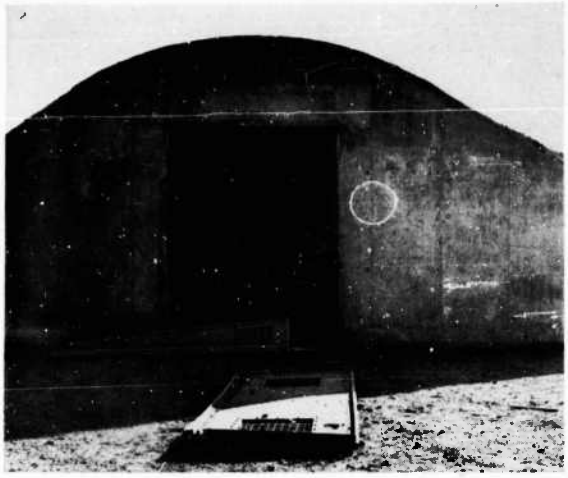
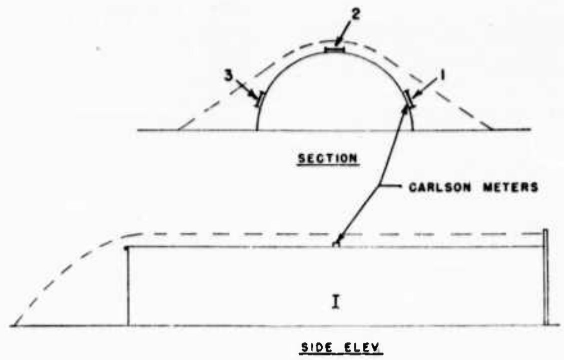


FIGURE 70. Target Igloo C after explosion of Test 2, showing doors blown off.



No. 1—6′7″ (horizontal distance) west of longitudinal center line (on side toward blast).
No. 2—longitudinal center line.
No. 3—6′7″ (horizontal distance) east of longitudinal center line (on side away from blast).

FIGURE 71. Installation of Carlson Meters on Igloo C, Test 2.

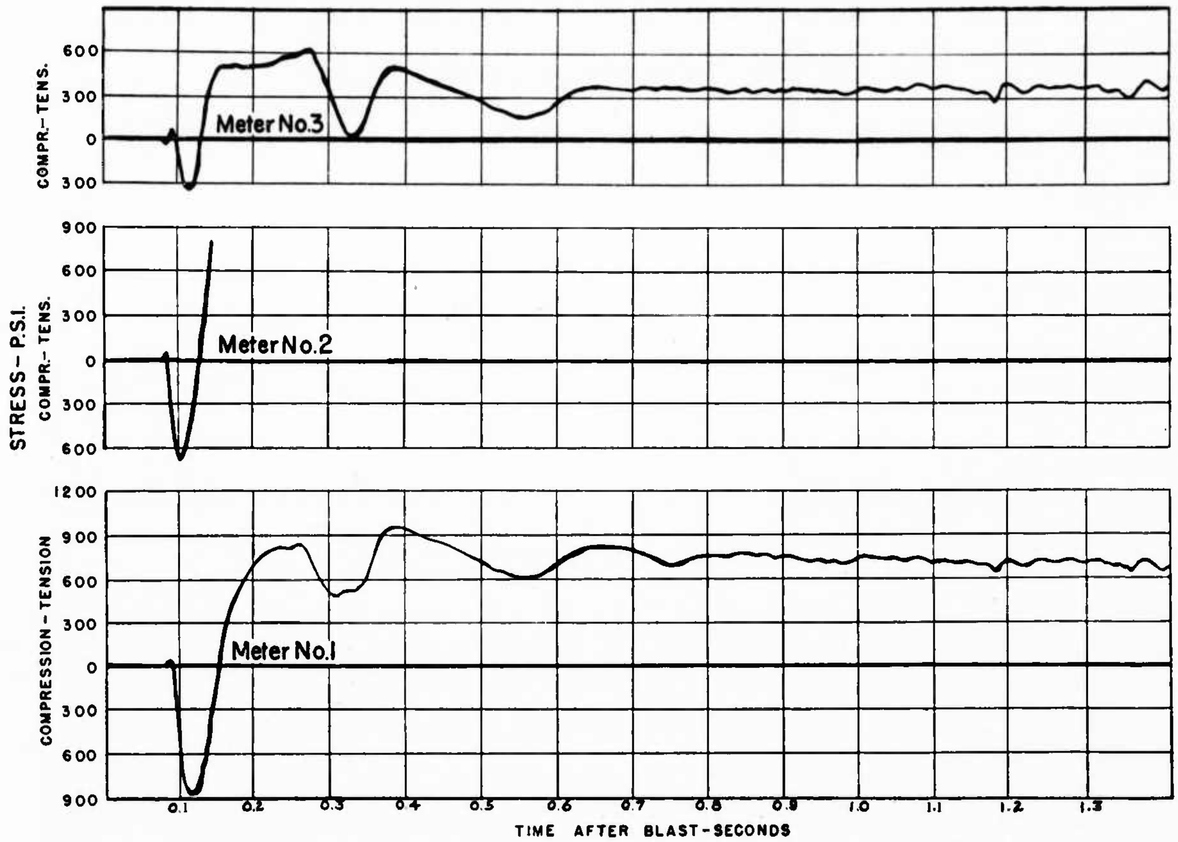


FIGURE 72a. Target igloo strain curves, Test 2.

FIGURE 72b. Carlson Strain Meter No. 2 installed showing crack.

C.—H. E. IGLOO TEST NO. 3—19 OCTOBER 1945

1. Purpose

a. To determine if the mass detonation of 250,000 net pounds of high explosives stored in a Navy test Igloo C will propagate to an earth barricaded open storage site (Revetment 2), loaded with 125,000 net pounds of high explosives, located parallel to and 185 feet from Igloo C, or to an Army Igloo B located diagonally to the rear and right of Igloo C at a distance of 280 feet.

b. To determine the severity of the damage done to the target igloos, revetments and their contents, to a Navy Igloo D with door barricade located diagonally in the rear and left of Test Igloo C at a distance of 752 feet, and to a wooden barracks building E located diagonally to the rear and right of Igloo C at a distance of 2,400 feet.

c. To record data pertaining to air blast pressures, seismic action, and crater size.

2. Test layouts

This test involved the explosion of 250,000 pounds of Torpex in Navy-type Test Igloo C *vs.* Revetment 2, Igloos B and D, and Navy-type Barracks, located as shown in figure 73. The doors of Igloo C were braced in place for this test.

3. Igloo and revetment contents

a. Igloos C and B were each loaded with five hundred and forty-one 650-pound Aircraft Depth Bombs, Mark 49, explosive charge 462 pounds of Torpex, for a total of 250,000 pounds of high explosives. These bombs were stored as shown in figure 16.

b. Revetment 2 was loaded with two hundred and eight 1,100-pound and nine 600-pound bombs containing 125,000 net pounds of 50/50 Amatol. These bombs were stored on wooden dunnage as shown in figures 65a, 65b, and 65c.

c. Igloo D was not loaded.

4. Priming

The depth bombs in each quarter of the magazine were primed in the following manner: Composition C-2 and primacord were placed in either the

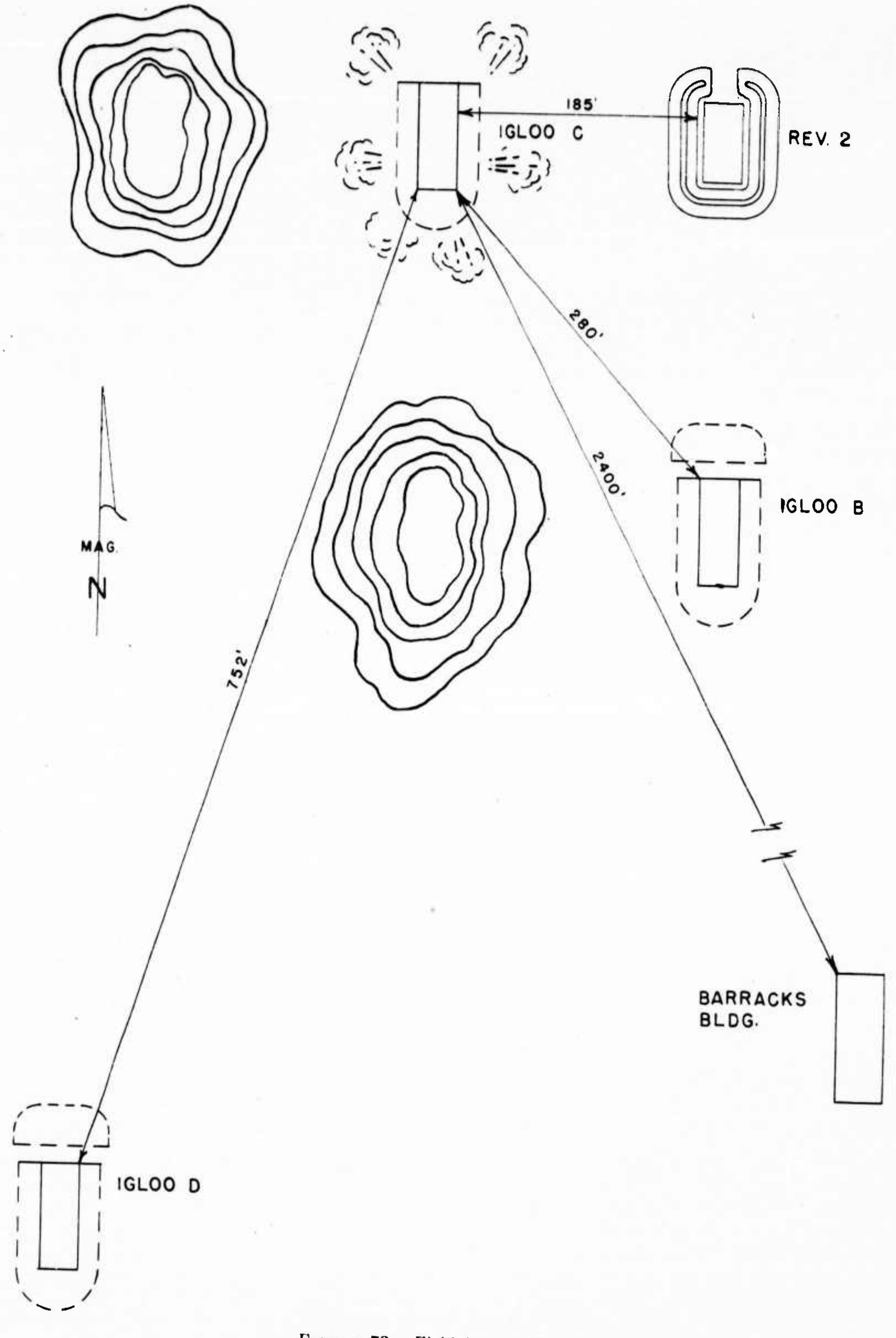


FIGURE 73. Field layout, Test 3.

FIGURE 74a. Explosion of Igloo C, Test 3, 1st stage

FIGURE 74b. Explosion of Igloo C, Test 3, 2d stage.

nose or tail fuze cavity of fourteen bombs in the stack and connected to a single primacord lead that passed to the center of the magazine where it joined the leads from the stacks in the other three quarters of the igloo which were similarly primed. A single primacord lead was taken from this junction and passed out the door of the igloo. Three Engineer Special electric blasting caps were connected to this lead and the caps were connected to the firing circuit in parallel.

5. Description of test and summary of results

a. General.—Igloo C was exploded at 1,215 MWT on 19 October 1945. The explosion of the 250,000 pounds of Torpex in Igloo C produced an initial red flash and then streamers of smoke that shot out and up at angles above 30° from the horizontal, forming a bush-like cloud that finally developed into a billowing black mass of smoke and dust as in Test 1 (figs. 74a and 74b). There was no propagation of the explosion from Igloo C to the target units, but Igloo B and Revetment 2 were damaged. Igloo D was undamaged. The barracks building was more severely damaged than during the previous tests (Nos. 1 and 2).

b. Motion picture record.—Motion pictures were obtained which show the explosion of the 250,000 pounds of Torpex in Igloo C at normal film speed.

c. Air blast pressures.—Air blast pressures were recorded only with paper blast meters, which were located as shown in figure 75. The pressures recorded are shown in table XIII.

d. Crater data.—The explosion of the contents of Igloo C produced an oval crater 156 feet long by 128 feet wide with an apparent depth of 17.8 feet (see figs. 76a and 76b). Apparent crater profiles along the longitudinal and transverse axes of the igloo and contours are shown in figure 77. The crater was considerably deeper than the crater from the explosion in Test 1.

e. Ground movement.—No measurements of ground movement were made.

f. Effect of blast on target igloos and revetment.

(1) Igloo B at 260 feet, diagonally to the rear of Igloo C, developed three horizontal cracks in the front wall on either side of the door. Two diagonal cracks also appeared in the front wall near the point at which the arch joins the front wall. The cracks started at about ground level at the extreme ends of the arch and extended convergently upward, roughly following the curvature of the arch. A few timbers were blown from the earth door barricade and the earth fill slumped slightly (see fig. 78). Igloo D was undamaged.

(2) Revetment 2, figure 79, was damaged by the explosion. The wall of the revetment closest

TABLE XIII.—*Test No. 3—19 October 1945—air blast pressures paper meters*

Distance, feet*	Pressure range in p. s. i.		Remarks	
	North line (off front)	West line (off side)	North line	West line
462	7.7	12.6	Blown over	Blown over.
488	12.6	7.7	do	Do.
517	7.7	7.7	do	Do.
548	7.7	7.7	do	Do.
582	7.7	7.7	do	Do.
615	7.7	7.7	do	Do.
650	5.8	7.7	do	Do.
691	5.8	5.8	do	Do.
731	7.7	7.7	do	Do.
775	5.8	7.7	do	Do.
820	5.8	5.8	do	Do.
868	3.6	7.7	do	Do.
921	3.6	5.8	do	Do.
975	3.6	3.6	do	Do.
1,030	2.7	3.6	do	Do.
1,100	1.8	3.6	do	Do.
1,160	3.6	3.6	do	Do.
1,230	1.8	2.7		Do.
1,300	2.7	3.6		Do.
1,370	2.7	2.7		
1,460	2.7	2.7		Blown over.
1,550	1.2	2.7		
1,640	1.2	2.7		
1,740	1.2	2.7		
1,840	1.2	1.8		
1,940	1.2	1.8		
2,060	1.2	1.8		
2,180	1.2	1.8		
2,310	.8	1.2		
2,450	1.2	1.2		
2,600	.8	1.2		
2,740	.8	1.2		
2,900	.8	.8		
3,080	.6	.4		
3,270	.6	.6		
3,460	.4	.4		
3,660	.4	.6		
3,880	0	0		
4,120	0	0		
4,350	0	0		

*This distance, for the West line, was measured from the corner formed by the front and west side of Igloo C, and for the North line from the center of the door of Igloo C (see fig. 75).

to Igloo C slumped and was partly blown away. Some of the bombs in the revetment were shaken from their dunnage and dunnage was thrown short distances. None of the bombs were damaged.

g. Damage to barracks.

(1) The barracks had not been repaired following Tests 1 and 2, but a comparison of the photographs of the damage done to the barracks after Test 1 (figs. 29 to 53) with photographs of the damage done to the barracks after this explosion (figs. 80, 81, 82, 83, and 84) shows that it suffered very severe structural damage during this test.

(2) On the end nearest the explosions (figs. 30 and 80) studding was broken and torn loose from the top plate, the top plate was torn and broken loose in two places, sheathing was torn off, one rafter was broken, and the stairway was broken loose from the building.

(3) On the end away from the explosion (figs. 31, 44, 81, 82, and 83) the top plate was torn loose at the east corner, the second floor plate was torn loose, sagged, and moved outward, the second floor wall was left hanging on the rafters and several rafters were cracked.

(4) A comparison of figures 29, 32, 81, and 83 will show that many additional window frames were blown out on the east and west sides.

h. Missile data.—Not recorded.

i. Seismological data.—Seismological data for this test are given in table XIV.

TABLE XIV.—*Test No. 3—19 October 1945—seismological data (Ref. 7)*

Distance from Igloo C, in feet	Explosives weight in pounds	Wave period, secs.	Maximum displacement, cm.	Maximum acceleration, cm/sec.^{2}	Remarks
2,840	250,000	0.17	0.016	20	Rock.
2,840	250,000	.17	.015	20	Overburden.
5,600	250,000	.22	.0067	5.5	Do.
5,600	250,000	.37	.015	4.5	Do.
9,200	250,000	.22	.003	2.5	Do.
9,200	250,000	.48	.008		Do.
11,850	250,000	.43	.005	1	Do.
22,000	250,000	.65	.0028	.27	Do.

j. Meteorological data.—Not recorded.

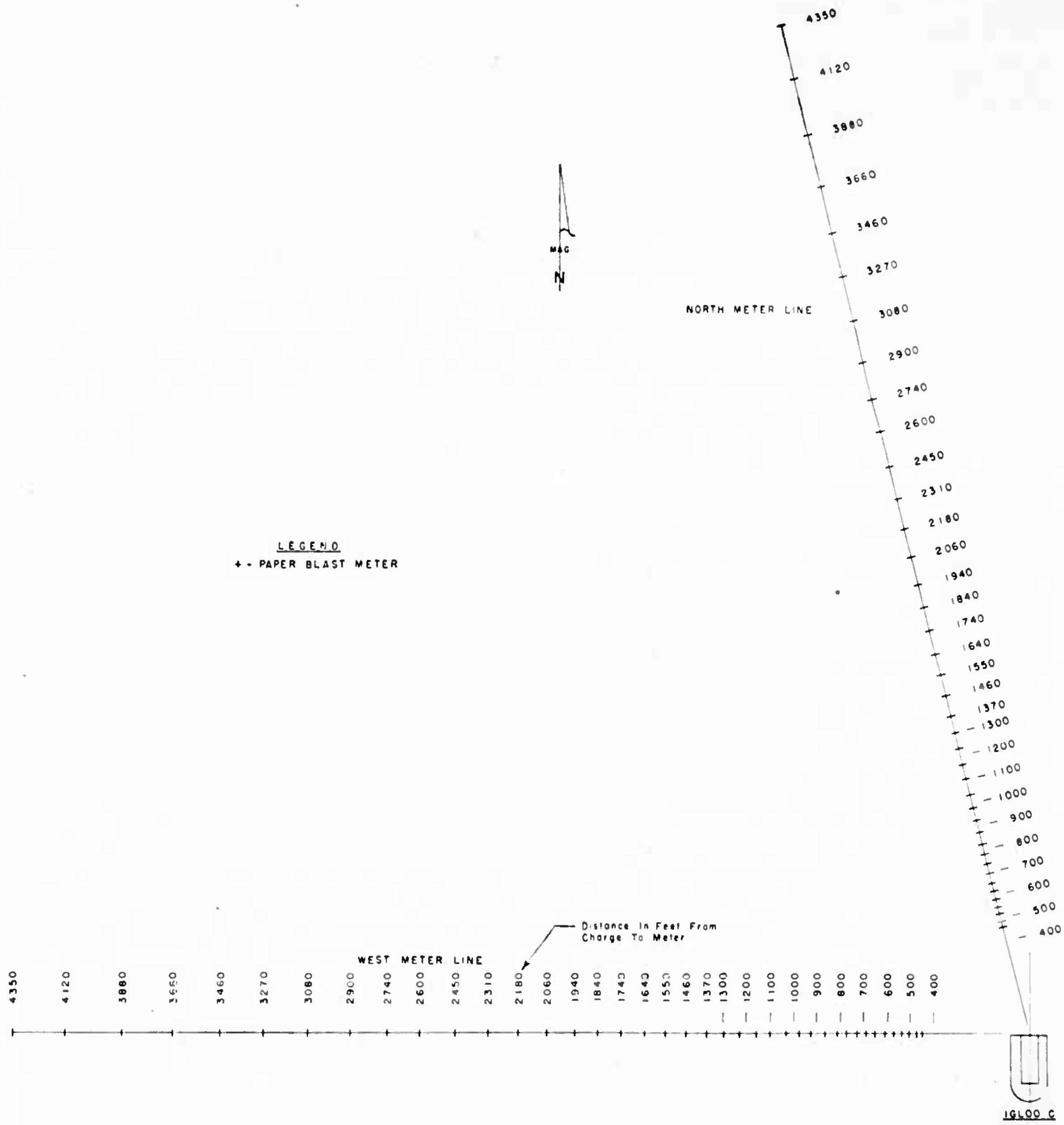


FIGURE 75. Location of paper blast meters, Igloo C, Test 3.

FIGURE 76a. Crater, Igloo C, Test 3—longshot.

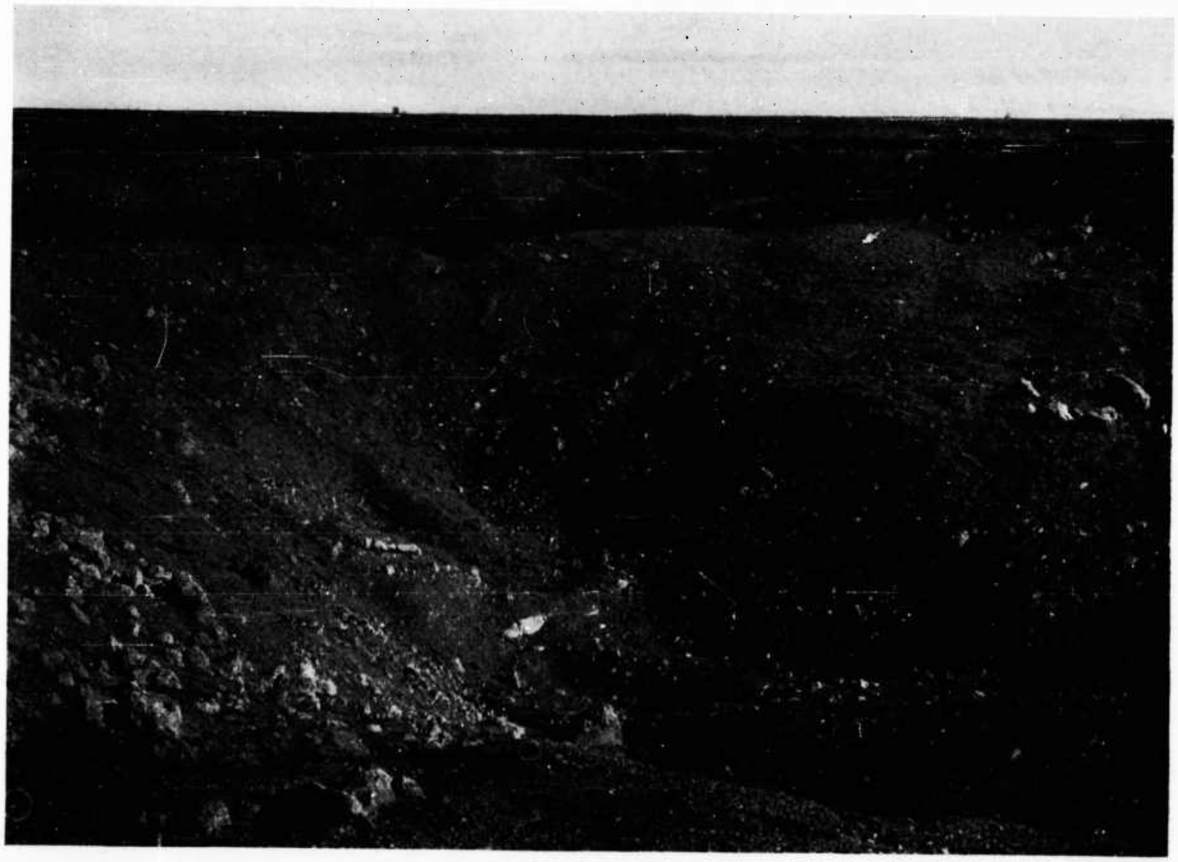


FIGURE 76b. Crater, Igloo C, Test 3—closeup.

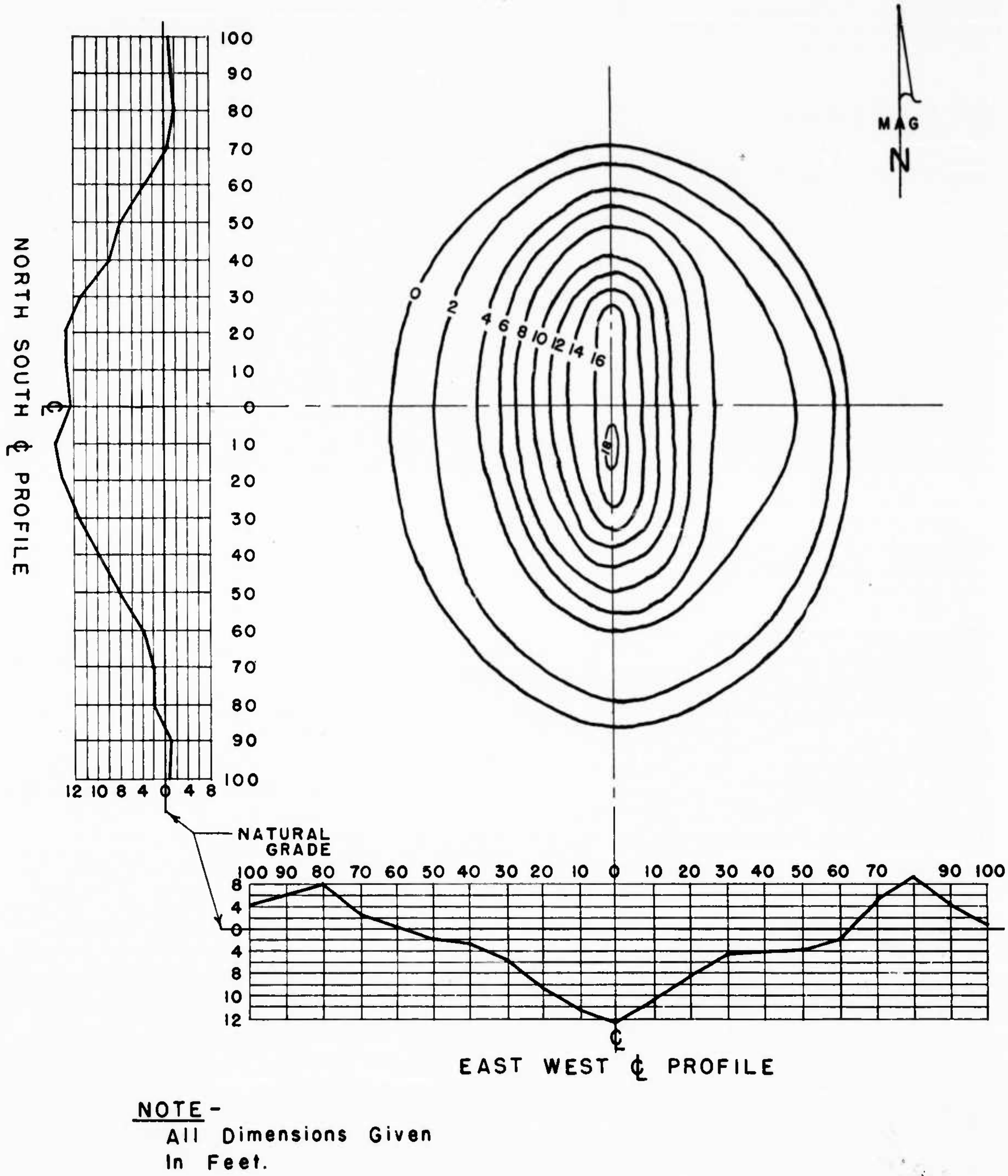


FIGURE 77. Crater plan and profiles, Igloo C, Test 3.

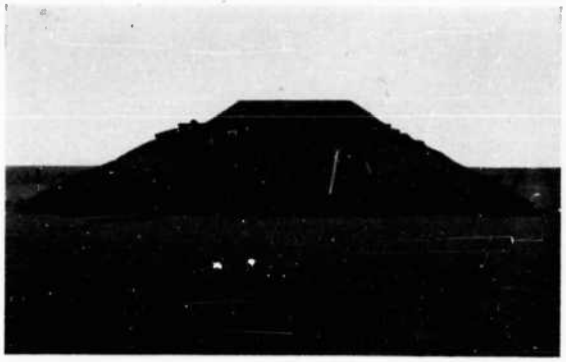


FIGURE 78. Damage to earth fill, Target Igloo B, Test 3.

FIGURE 79. Damage to revetment 2 and displacement of bombs, Test 3.

FIGURE 80. Barracks damage, Test 3.

FIGURE 81. Barracks damage, Test 3.

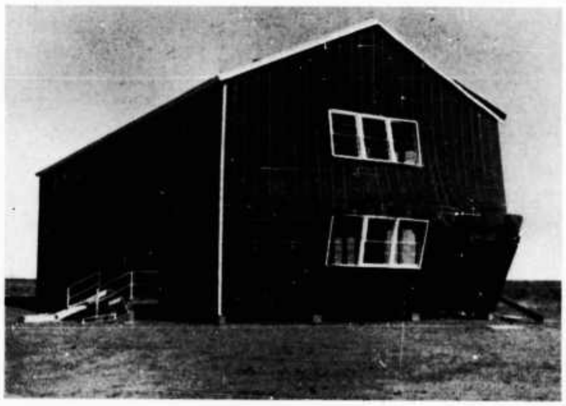


FIGURE 82. Barracks damage, Test 3.

FIGURE 83. Barracks damage, Test 3.

FIGURE 84. Barracks damage, Test 3.

D.—H. E. IGLOO TEST NO. 4—30 OCTOBER 1945

1. General

After Test No. 3, an earth barricaded open storage site (revetment) was constructed on the site of Igloo A which was destroyed in Test No. 1. The crater made by the explosion of Igloo A was filled in, and the fill was compacted and levelled to form as firm a foundation for the revetment as possible. It was, however, not equal to the virgin ground on which Igloo A was built. Revetment No. 2 was repaired and the bombs it contained were restored.

2. Purpose

a. To determine if the mass detonation of 250,000 net pounds of high explosives stored in an earth barricaded open storage site, Revetment 3, will propagate to an Army Igloo B loaded with 250,000 net pounds of high explosives and located parallel to and 185 feet from Revetment 3; or to another earth barricaded open storage site, Revetment 2, loaded with 125,000 net pounds of high explosives and located diagonally to the right and front of test Revetment 3 at a distance of 293 feet.

b. To determine the severity of the damage done to the above target igloos, revetments, and their contents, to a Navy Igloo D with door barricade located diagonally to the rear and left of test Revetment 3 at a distance of 510 feet, and to a wooden barracks building E located diagonally to the rear and right of test Revetment 3 at a distance of 2,165 feet.

c. To record data pertaining to air blast pressures, seismic action, and ground movement.

3. Test layout

This test involved the explosion of 250,000 pounds of 50/50 Amatol in Revetment 3 *vs.* target units Igloos B and D and Revetment 2, located as shown in figures 85 and 86. The Bureau of Reclamation placed strain gages in and on Igloo B to measure the deformation of that igloo as a result of the explosion of Revetment 3. The U. S. Coast and Geodetic Survey placed one seismic instrument in the instrument shelter (fig. 2).

4. Revetment and igloo contents

a. Revetment 3 was loaded with seven hundred and eighty-three 600-pound bombs, explosive charge 320 pounds of 50/50 Amatol, for a total of 250,000 pounds of high explosives stacked as shown in figure 87.

b. Igloo B was loaded with five hundred and forty-one 640-pound Aircraft Depth Bombs, Mark 49, explosive charge 462 pounds of Torpex,

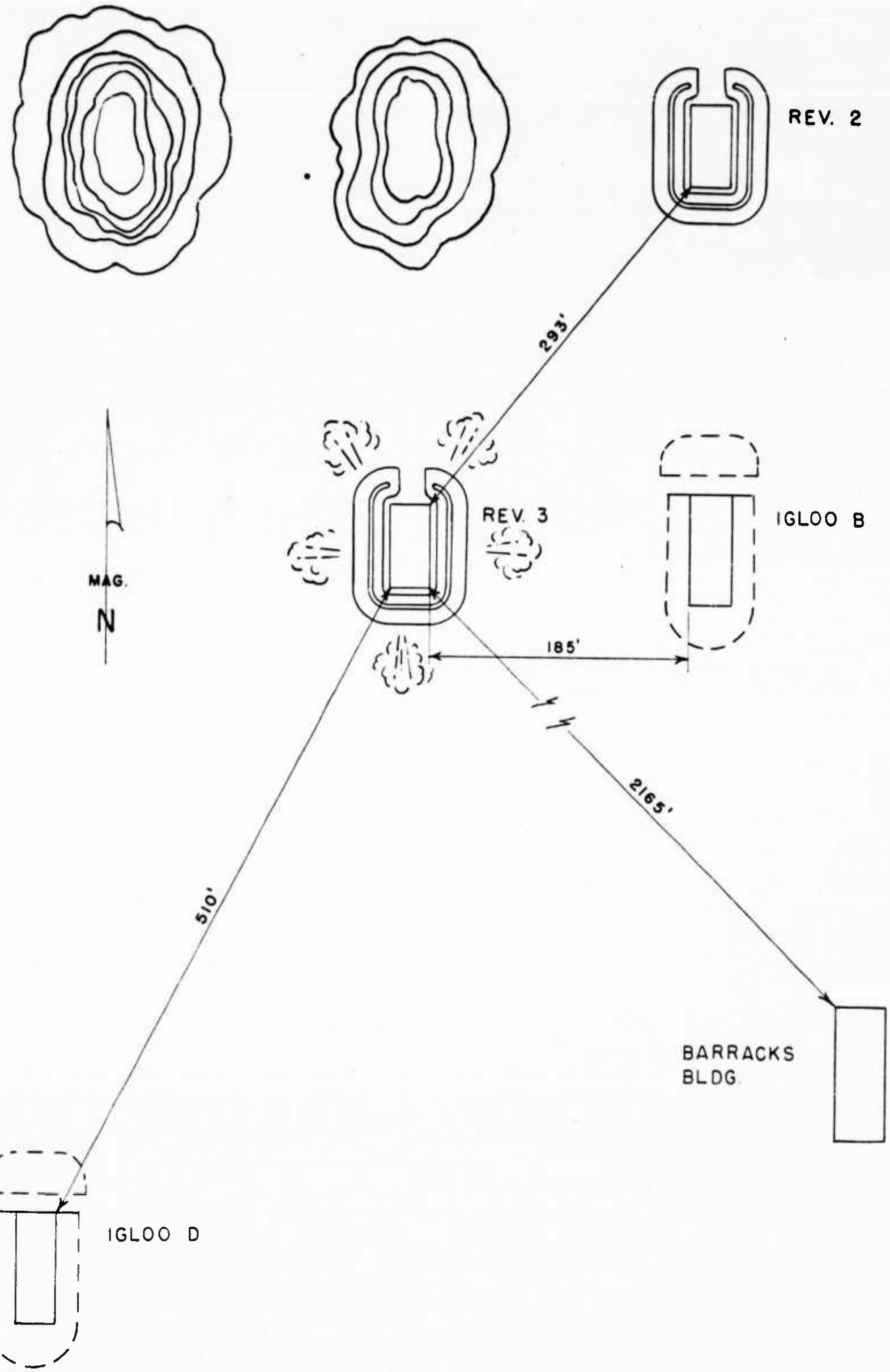


FIGURE 85. Field layout, Test 4.

FIGURE 86. Revetment 3 and Igloo B, Test 4.

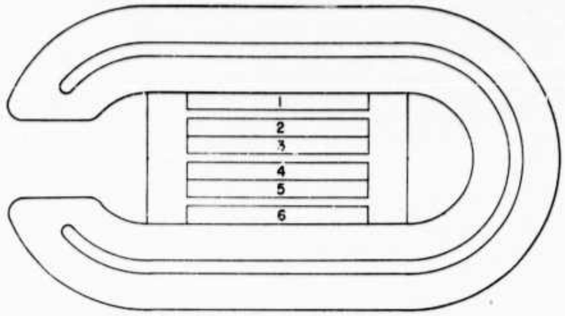


FIGURE 87. Revetment storage diagram, Test 4.

for a total of 250,000 pounds of high explosives. These bombs were stored as shown in figure 16. Igloo D was not loaded.

c. Revetment 2 was loaded with two hundred and eight 1100-pound and nine 600-pound bombs, explosive charge 50/50 Amatol, for a total of 125,000 pounds of high explosives. These bombs were stored as shown in figures 65a, 65b, and 65c.

5. Priming

Approximately half the bombs in Stacks 1 and 5 of Revetment 3 were primed by packing knotted primacord surrounded by Composition C–2 into the nose fuze cavity of each bomb in the same manner as in Test 2. All primed bombs in each stack were connected to a single primacord lead which passed down the side of the stack, and the two primacord leads joined at the rear of the revetment. Three Engineer Special electric blasting caps were connected to the leads at this junction and the caps were connected to the firing circuit in parallel.

6. Description of test and summary of results

a. General.—Revetment 3 was exploded at 0920 on 30 October 1945. The explosion of the 250,000 pounds of Amatol in Revetment 3 produced more flame than the igloo explosions and the dense black smoke cloud rose in a mushroom shape with a boiling crest of smoke and flame above a column of smoke (fig. 88). There was no propagation of the explosion of Revetment 3 to the target units, but Igloo B and the barracks were damaged further.

b. Motion picture record.—Motion pictures were obtained which show the explosion of the 250,000 pounds of Amatol in Revetment 3 at normal film speed.

c. Air blast pressures.—Air blast pressures were measured by a north and west meter line of paper blast meters, located as shown in figure 89. The pressures recorded are shown in table XV.

d. Crater data.—No crater measurements were made because the revetment had been placed on back-filled ground.

e. Ground movement.—Ground movements were recorded to the front, rear, and west side in this test (fig. 90).

f. Effect of blast on target igloos and revetment.

(1) Igloo B received additional damage from the explosion of Revetment 3 but its contents were undisturbed. The door jammed and concrete spalled off the top of the arch where it joined the front wall exposing reinforcing rod for a distance of about 4 inches longitudinally and for a length of about 6 feet transversely. Concrete also spalled off the inside of the door frame uncovering some reinforcing rod. A few timbers were displaced in the door barricade and some of the earth was blown away. A fine crack appeared on the arch of Igloo D following the explosion. The crack was about half way back from the door of the magazine. It passed completely across the arch. Revetment 2 was undamaged.

(2) The Bureau of Reclamation installed Carlson gages (Ref. 4) on Igloo B as shown in figure 91. The records of these gages are shown in figure 92. No stress scale is shown for Meter 2 because the meters were calibrated after the blast and Meter 2 failed in tension during the test. The first earth shock appeared at about 0.075 second, indicating a velocity of about 2,600 feet per second (using 197 feet as the distance of travel). Speed of travel of the air wave was apparently only slightly less than that of the ground wave. Meter 1 shows that the longitudinal compression in the

TABLE XV.—*Test No. 4—30 October 1945—air blast pressures, paper meters*

Distance from side or front of Rev. No. 3, in feet	Pressure range in p. s. i.		Remarks	
	North line (off front)	West line (off side)	North line	West line
462	7. 7	7. 7	Blown apart	Blown over.
488	5. 8	7. 7	Blown over	Do.
517	5. 8	7. 7	do	Do.
548	5. 8	7. 7	do	Do.
582	7. 7	7. 7	do	Do.
615	7. 7	7. 7	do	Do.
650	5. 8	7. 7	do	Do.
691	3. 6	5. 8	do	Do.
731	2. 7	3. 6	do	Do.
775	3. 6	3. 6	do	Do.
820	3. 6	3. 6	do	Do.
868	3. 6	3. 6	do	Do.
921	3. 6	2. 7	do	Do.
975	2. 7	3. 6	do	Do.
1,030	1. 8	2. 7		
1,100	2. 7	2. 7	do	
1,160	1. 8	2. 7		
1,230	1. 8	3. 6		
1,300	1. 2	1. 8		
1,370	1. 2	3. 6		
1,460	1. 2	1. 2	do	Do.
1,550	. 8	1. 8		
1,640	1. 2	1. 8		
1,740	. 8	1. 2		
1,840	. 8	. 8		
1,940	. 6	1. 2		
2,060	. 6	1. 8		
2,180	. 8	1. 2		
2,310	. 6	. 8		
2,450	. 6	. 8		
2,600	. 6	. 8		
2,740	. 4	. 8		
2,900	. 6	. 4		
3,080	. 4	. 6		
3,270	0	. 6		
3,460	0	. 6		
3,660	0	. 6		
3,880	0	0		
4,120	0	. 4		
4,350	0	. 4		

dome reached 800 p. s. i. during the positive pressure phase, and that some compression was maintained for about 0.10 second. Evidently the positive phase of the pressure wave placed a compressive load on the ends of the igloo, but somewhat surprisingly, the longitudinal stress then returned to zero without passing into tension. Meter 2, located on the side of the igloo away from the blast, showed transverse compression of

FIGURE 88. Explosion of revetment 3, Test 4.

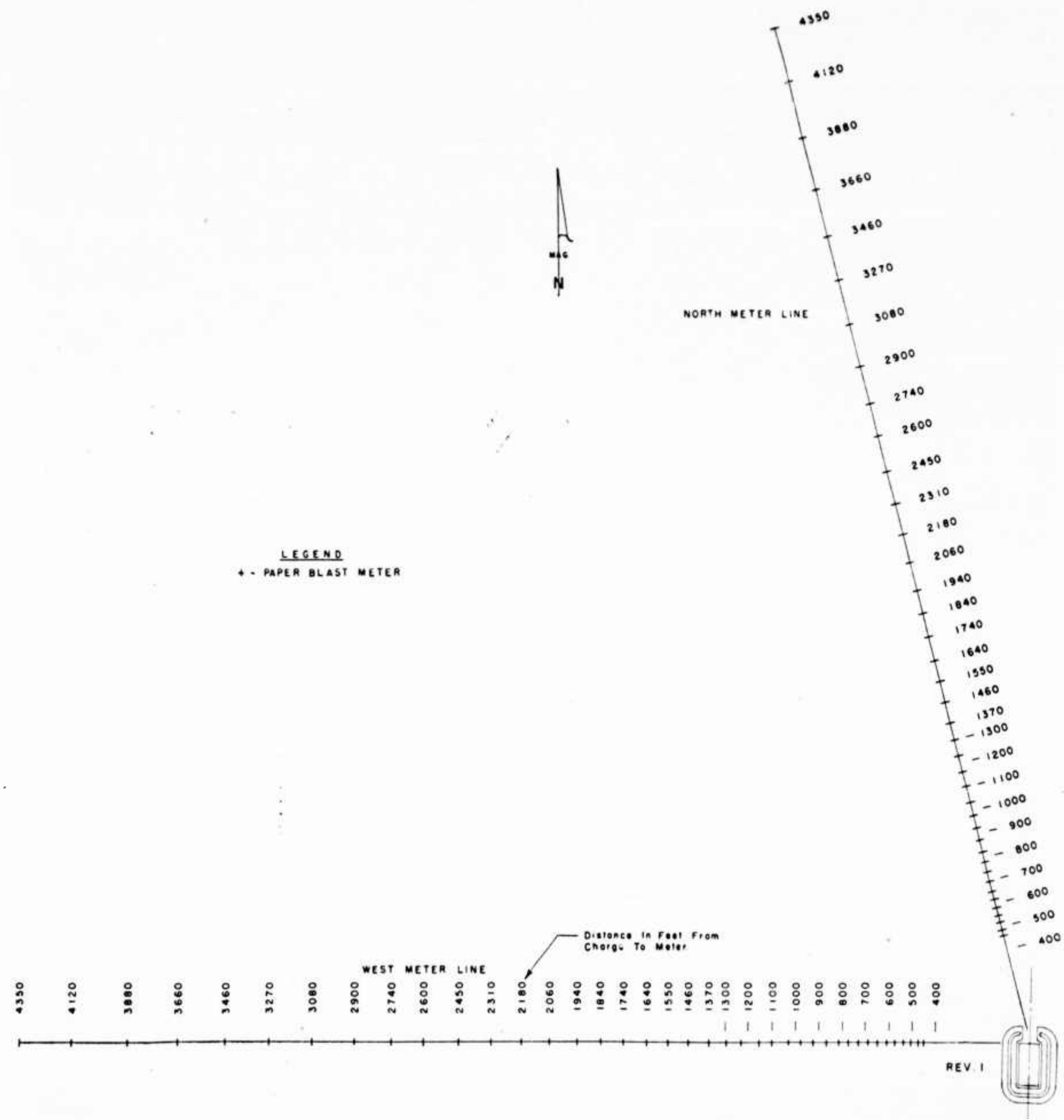


FIGURE 89. Location of paper blast meters, Test 4.

about 0.02 second duration followed by rapid development of tension until failure occurred. Time was not available between this test and the later destruction of the igloo on the same day to permit an inspection of the area for cracking. The single measurement made on the floor (Meter 3) does not provide sufficient information for an accurate interpretation. During the positive wave phase the floor showed about 125 p. s. i. transverse tension followed later by about 175 p. s. i. compression and finally a residual tension of about 300 p. s. i. It seems probable that the floor stresses are influenced more by ground movement than by air waves, and that the residual tension is a result of unequal settlement following the ground disturbance caused by the blast.

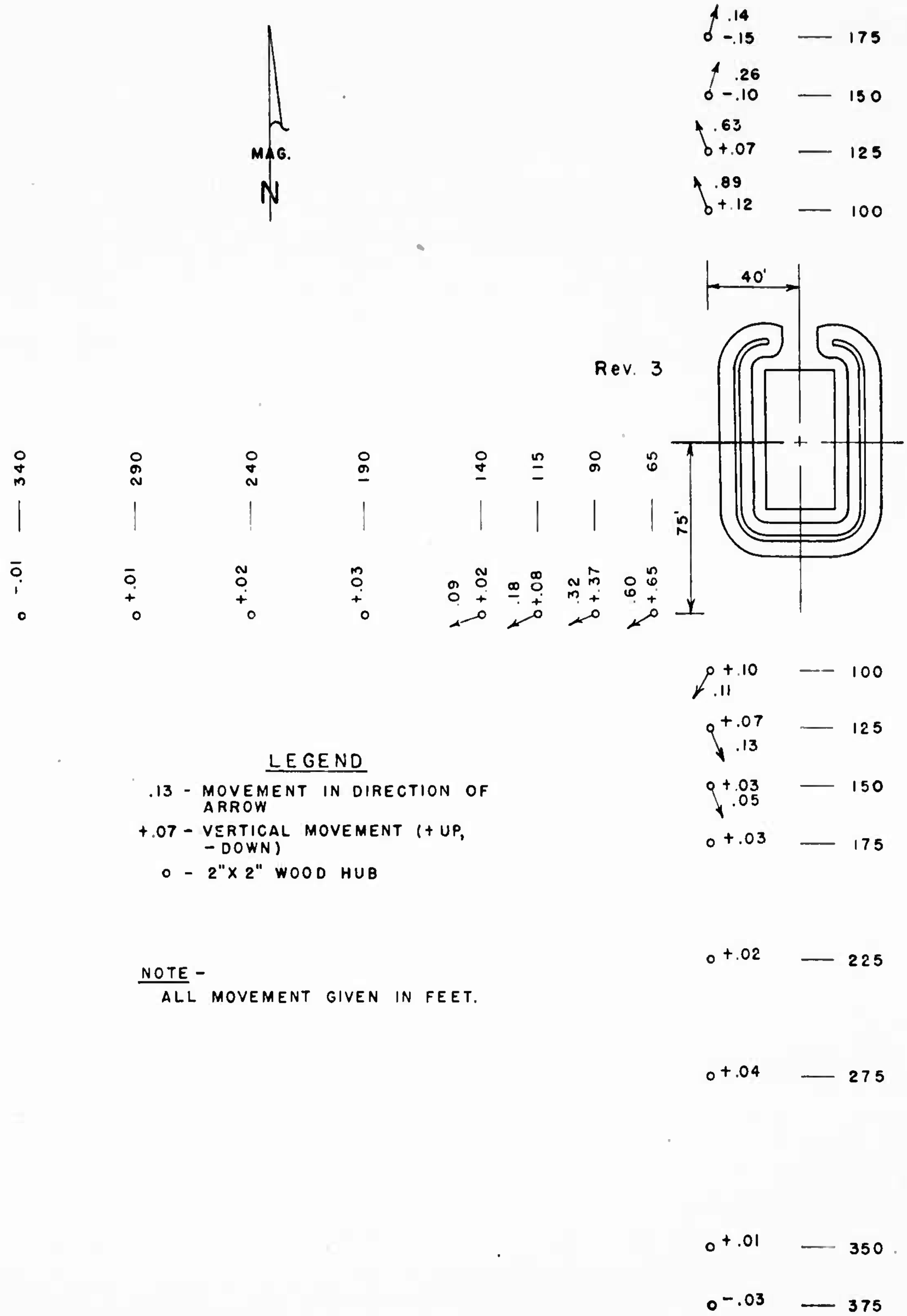
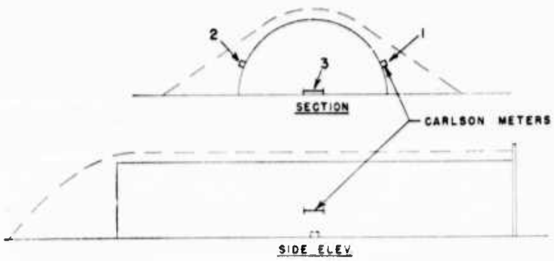


FIGURE 90. Permanent horizontal and vertical earth displacement, Test 4.



No. 1—6.7″ (horizontal distance) west of the longitudinal center line, direction parallel to longitudinal center line.
No. 2—6.7″ (horizontal distance) east of the longitudinal center line, direction, transverse to the longitudinal center line.
No. 3—On the igloo floor on the longitudinal center line, direction transverse to the longitudinal center line.

FIGURE 91. Installation of Carlson Meters on Igloo B, Test 4.

g. Damage to barracks (barracks previously damaged by Tests 1, 2 and 3 and not repaired).—The barracks building suffered still further damage as a result of this test. The first floor south wall (away from explosion), which had broken loose at the east corner in Test 3, collapsed outward. The second floor south wall was left hanging on the rafters, approximately 10 of which were broken on either side of the peak at that end. The north end (end toward explosion) was further damaged with additional sheathing torn loose and studding broken. The west wall was pulled out and the railing on the front steps (west side) was broken loose.

h. Missile data.—Not recorded.

i. Seismological data (Ref. 7).—Seismological data recorded are given in table XVI.

TABLE XVI.—*Test No. 4—30 October 1945—seismological data*

Distance from Revetment 3 in feet	Explosives weight in pounds	Wave period in sec.	Maximum displacement in cm.	Maximum acceleration, cm/sec.²
650	300, 000	0. 15	0. 29	510

j. Meteorological data.—Not recorded.

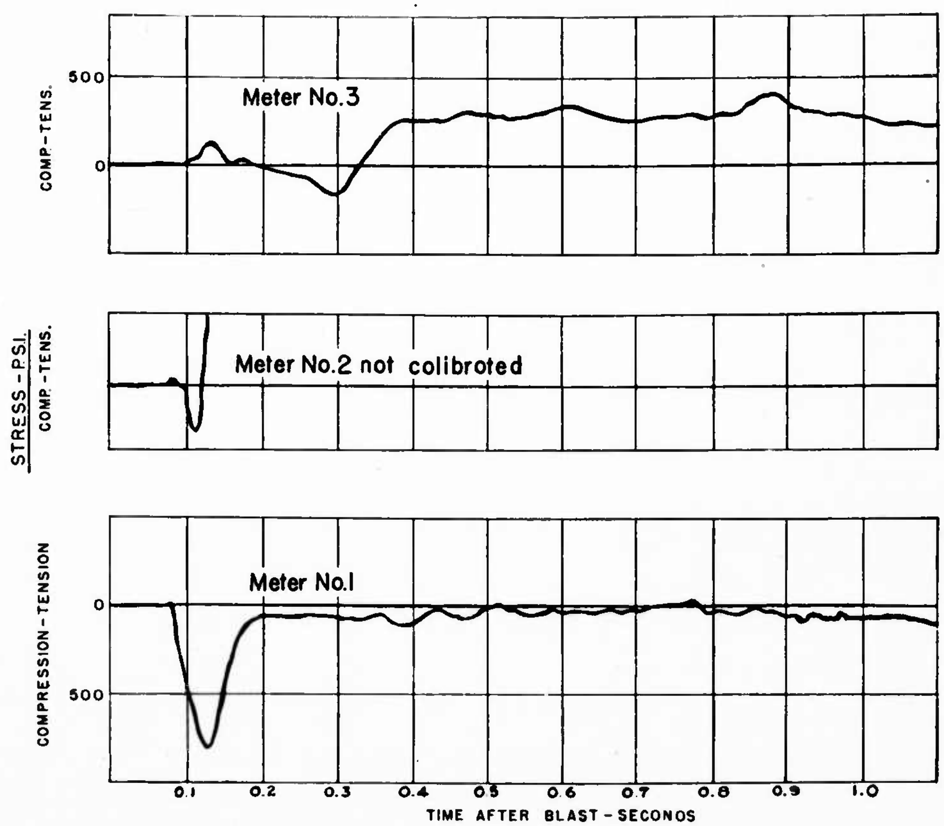


FIGURE 92. Target igloo stress curves, Test 4.

E.—H. E. IGLOO TEST 5—30 OCTOBER 1945

1. Purpose

a. To determine if the mass detonation of 250,000 net pounds of high explosives stored in an Army test Igloo B will propagate to an earth barricaded open storage site, Revetment 2, located in line with the test igloo and 230 feet in front of it.

b. To determine the severity of the damage done to target Revetment 2 and a Navy Igloo D, located diagonally to the rear and left of Igloo B at a distance of 620 feet, and to a wooden barracks building E located diagonally to the rear and right of the test Igloo B at a distance of 2,050 feet.

c. To obtain additional information on crater size.

2. Test layout

This test involved the explosion of 250,000 pounds of Torpex in Army Igloo B *vs*, target units, Revetment 2, Igloo D, and the Navy Barracks, located as shown in figure 93.

3. Igloo and revetment contents

a. Igloo B was loaded with five hundred and forty-one 650-pound Aircraft Depth Bombs, Mark 49, explosive charge 462 pounds of Torpex, for a total of 250,000 pounds of high explosives. These bombs were stored as shown in figure 16. Igloo D was not loaded.

b. Revetment 2 was loaded with two hundred and eight 1100-pound and nine 600-pound bombs, explosive charge 50/50 Amatol, for a total of 125,000 pounds of high explosives. These bombs were stored on wooden dunnage as shown in figures 65a, 65b, and 65c.

4. Priming

Igloo B was primed in a manner similar to that used in Igloo C, Test 3. Each quarter of the magazine was primed. Composition C-2 and primacord were placed in either the nose or tail fuze cavity of 14 bombs in the stack and connected to a single primacord lead that passed to the center of the magazine where it joined the leads from the stacks in the other three quarters of the igloo which were similarly primed. A single primacord lead was taken from this junction and passed out the door of the igloo. Three Engineer Special electric blasting caps were connected to this lead and the caps were connected to the firing circuit in parallel.

5. Description of test and summary of results

a. General.—Igloo B was exploded at 1250 MWT on 30 October 1945. The explosion of the 250,000 pounds of Torpex in Igloo B produced an initial red flash and then streams of smoke that shot out and up at angles above 30° from the horizontal, forming a bush-like cloud that developed into a billowing black mass of smoke and dust as in Tests 1 and 3 (figs. 94a and 94b). There was no propagation of the explosion from Igloo B to the target units and Igloo D and Revetment 2 were undamaged by the explosion. The barracks building was further damaged.

b. Motion picture record.—Motion pictures were obtained which show the explosion of the 250,000 pounds of Torpex in Igloo B at normal film speed.

c. Air blast pressures.—Not recorded.

d. Crater data.—The explosion of the contents of Igloo B produced an oval crater 158 feet long and 134 feet wide with an apparent depth of 10.7 feet. Profiles and contours of the crater from the explosion of Igloo B are shown in figure 95. This crater is approximately the same size but considerably shallower than the crater from Test 3.

e. Ground movement.—Not recorded.

f. Effect of blast on target igloos and revetment.—Igloo D was undamaged by the explosion. Several 600-pound bombs at the rear of Revetment 2 were shaken from their dunnage but the revetment was otherwise undamaged.

g. Damage to barracks.—The barracks was still standing after this test but had been so badly damaged by previous tests that no assessment of increased damage could be made.

h. Missile data.—Not recorded.

i. Seismological data.—Not recorded.

j. Meteorological data.—Not recorded.

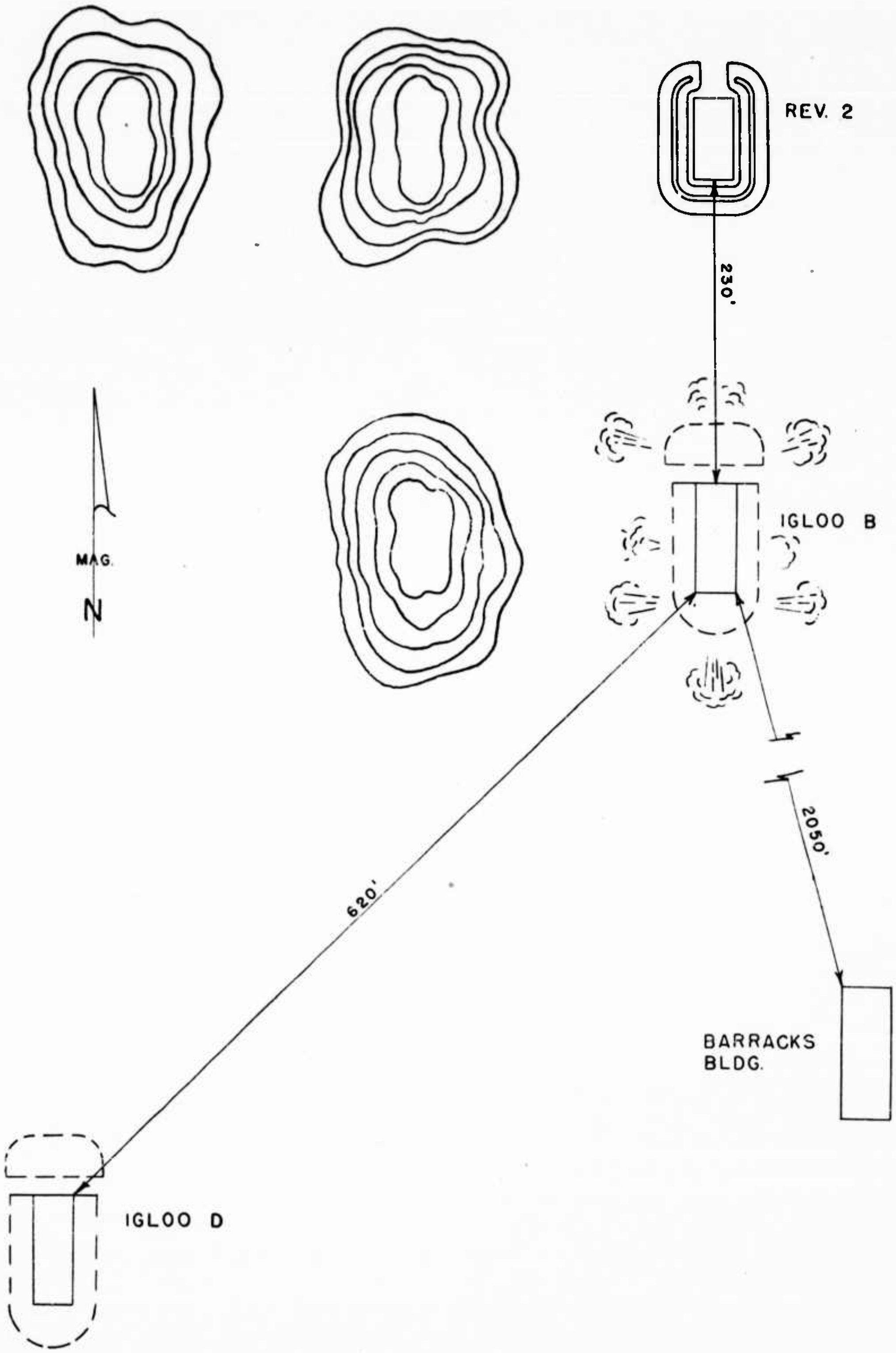


FIGURE 93. Field layout, Test 5.

FIGURE 94a. Explosion of Igloo B, Test 5, 1st Stage.

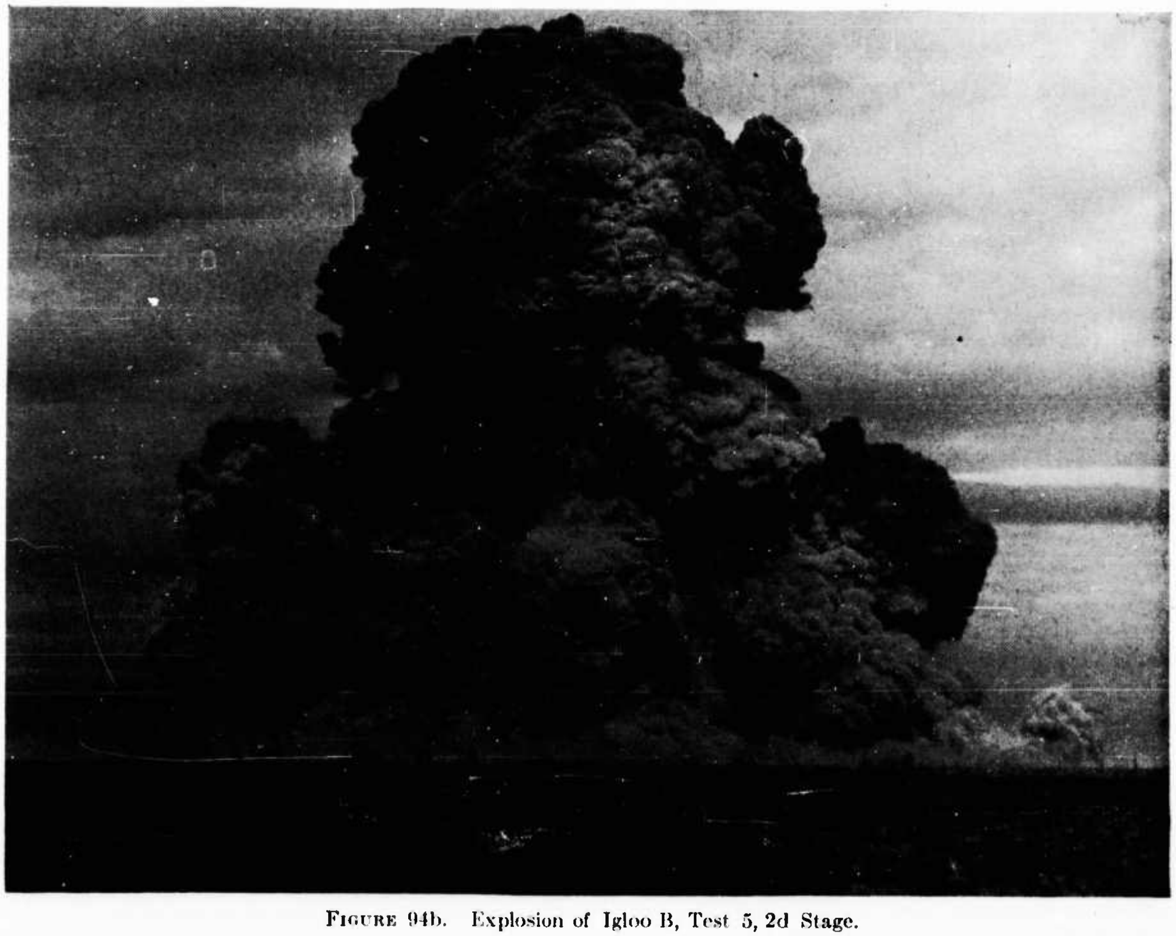


FIGURE 94b. Explosion of Igloo B, Test 5, 2d Stage.

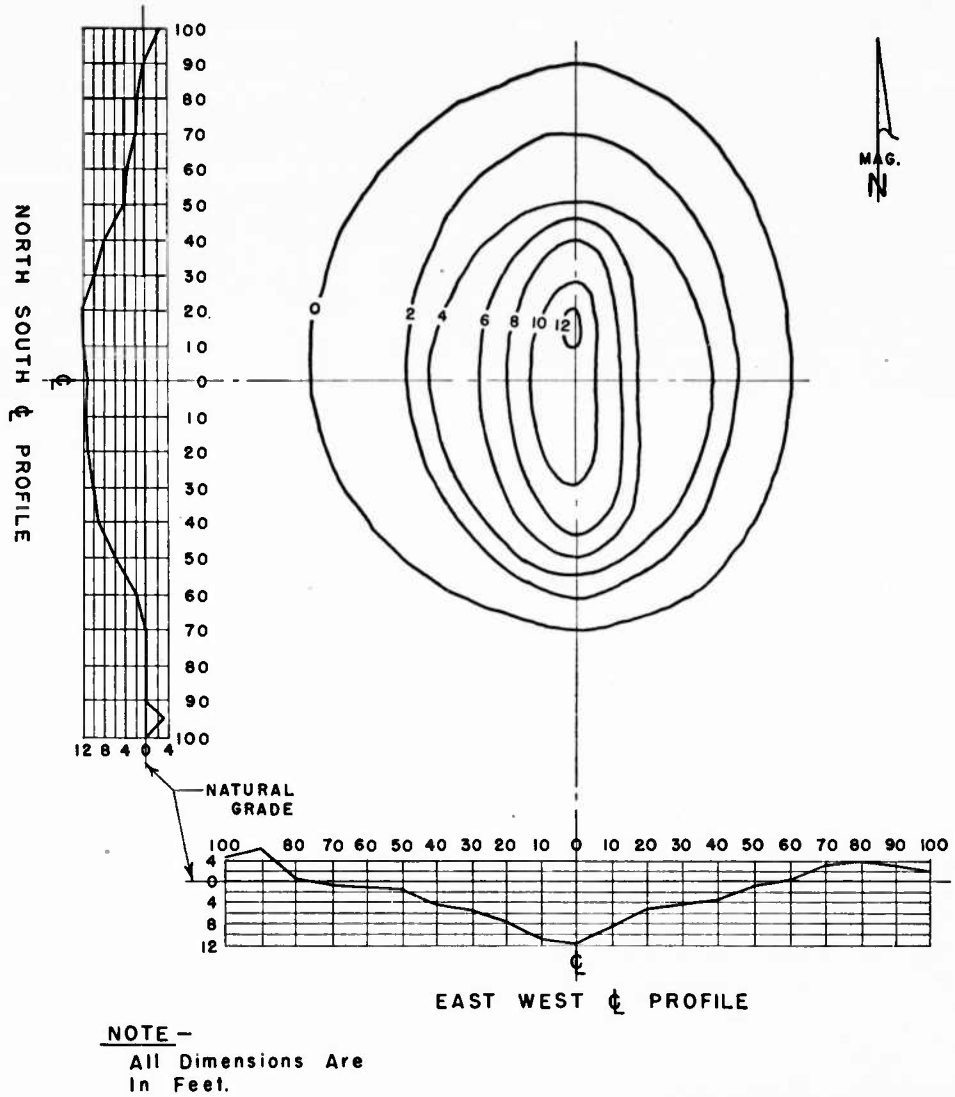


FIGURE 95. Crater plan and profiles, Igloo B, Test 5.

F.—H. E. IGLOO TEST 6—30 OCTOBER 1945

1. Purpose

To obtain additional crater information.

2. Test layout

This test involved the explosion of 125,000 pounds of 50/50 Amatol in an earth barricaded open storage site, Revetment 2, alone. (Igloo D was out of range of the effect of the blast)

3. Revetment contents

Revetment 2 was loaded with two hundred and eight 1,100-pound and nine 600-pound bombs, explosive charge 50/50 Amatol, for a total of 125,000 pounds of high explosives. These bombs were stored as shown in figures 65a, 65b, and 65c.

4. Priming

Approximately one-half of the bombs in Stacks 2 and 4 of Revetment 2 were primed by packing knotted primacord surrounded by Composition C–2 into the nose cavity of each bomb as in Test 2. A single primacord lead passed down the side of Stack 2 connecting all primed bombs in that stack and joined a similar lead from Stack 4 at the rear of the revetment. Three Engineer Special electric blasting caps were connected to the two leads and the caps were connected to the firing circuit in parallel.

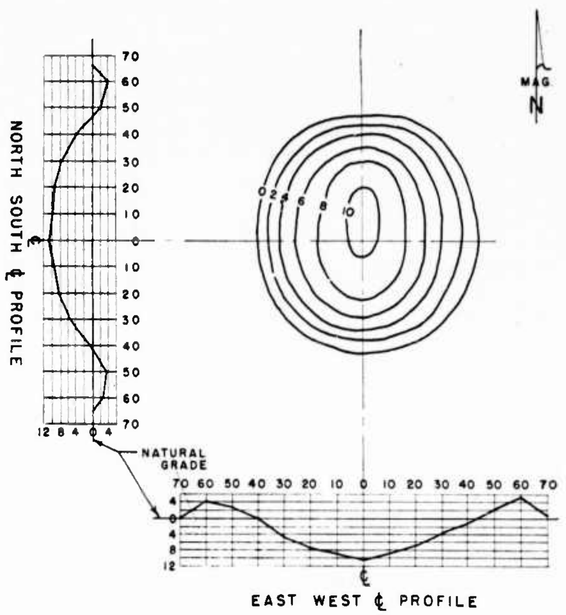


FIGURE 97. Crater plan and profiles, revetment 2, Test 6.

FIGURE 96. Explosion of revetment 2, Test 6.

5. Description of test and summary of results

a. General.—Revetment 2 was exploded at approximately 1500 on 30 October 1945. The explosion of the 125,000 pounds of Amatol in Revetment 2 provided an initial flash and considerable flame followed by a dense black smoke cloud that rose in a mushroom shape with a boiling crest of smoke and flame above a column of smoke (fig. 96).

b. Motion picture record.—Motion pictures were obtained which show the explosion of the 125,000 pounds of Amatol in Revetment 2 at normal film speed.

c. Air blast pressures.—Not recorded.

d. Crater data.—The explosion of the contents of Revetment 2 produced a crater 89 feet long and 87 feet wide with an apparent depth of 10.9 feet.

Contours and profile of the crater along the longitudinal and transverse axes of the revetment are shown in figure 97.

e. Ground movement.—Not recorded.

f. Effect of blast on targets.—Not recorded.

g. Damage to barracks and glass breakage.—Not recorded.

h. Missiles and fragmentation.—Not recorded.

i. Seismological data.—Not recorded.

j. Meteorological data.—Not recorded.

G.—H. E. IGLOO TEST 7—31 OCTOBER 1945

1. Purpose

To determine if the mass detonation of 250,000 net pounds of high explosives stored in an unbarricaded stack will propagate to another unbarricaded stack containing 250,000 net pounds of high explosives located parallel to and 800 feet from the test stack.

2. Test layout

This test involved the explosion of 250,000 pounds of explosives as listed below in an unbarricaded open storage stack. Two stacks of ammunition approximately 30 x 70 x 4½ feet were placed on level ground 800 feet apart (fig. 98).

3. Stack contents

a. Stack 1, the primary stack, contained 600-pound bombs, MK 9 depth charges, scrap TNT, Tetryl boosters, and bangalore torpedoes with a total weight of high explosives of 250,000 pounds. The 600-pound bombs were stacked three high in a hollow square and the other ammunition was piled inside.

b. Stack 2 was composed entirely of M1–A1 antitank mines without boxes. The mines were stacked 40 wide, 105 long, and 10 high, each mine resting on its base, with a total weight of high explosives of 250,000 pounds.

4. Priming

Stack 1 was primed using Composition C–2 and primacord in a manner similar to that used in all previous tests. Approximately 10 percent of the 600-pound bombs were primed in the nose fuze cavity and in addition a portion of the scrap TNT and other ammunition was primed. All the primed bombs, etc., were connected to a single primacord lead that passed completely around the stack and joined back onto itself. Three Engineer Special electric blasting caps were connected to the primacord at this junction and the caps were connected to the firing circuit in parallel.

5. Description of test and summary of results

a. General.—Stack 1 was exploded at 1240 on 31 October 1945. The explosion of the 250,000 pounds of high explosives in Stack 1 produced an initial flash and considerable flame and then the mushroom-shaped cloud with a boiling crest of smoke and flame above a column of smoke. There was no propagation of the explosion of Stack 1 to Stack 2. A high humidity at the time of the test made it possible to observe the movement of a rarefaction wave through the air. This wave apparently moved just ahead of the shock wave and was caused by the shock wave compressing the air which then condensed on cooling.

b. Motion picture record.—Not recorded.

c. Air blast pressure.—Not recorded.

d. Crater data.—The explosion of the contents of Stack 1 produced a crater 134 feet long, 86 feet wide, and 3.9 feet deep at the lowest point. Contours and profiles of the crater along the longitudinal and transverse axes of Stack 1 are shown in figure 99a. The unusual crater shape is probably due to the fact that the cased charges (bombs) were on the outside of the stack and correspond to the deeper parts while the bulk uncased explosives were in the center of the stack and correspond to the shallow portion of the crater.

e. Ground movement.—Not recorded.

f. Effect of blast on target stack 2.—Approximately 75 mines on the outside of Stack 2 fell over probably from ground shock, and two mines were perforated by fragments which did not melt any of the TNT filler. A few small metal fragments, some of which were warm, were found on the stack and numerous other small fragments were found on the ground near the stack.

g. Damage to barracks and glass breakage.—Not recorded.

h. Missiles and fragmentation.—Not recorded.

i. Seismological data.—Not recorded.

j. Meteorological data.—Not recorded.

H.—H. E. IGLOO TEST 8—31 OCTOBER 1945

1. Purpose

To obtain further crater data as a continuation of Test 7.

2. Test layout

In this test M1–A1 antitank mines, containing 250,000 net pounds of TNT, in unbarricaded Stack 2 were exploded alone (fig. 98).

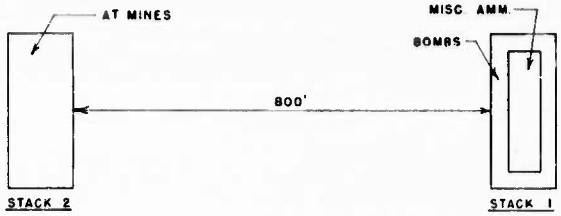


FIGURE 98. Field layout, Tests 7 and 8.

3. Stack contents

Stack 2 was composed entirely of M1–A1 antitank mines without boxes. The mines were stacked 40 wide, 105 long, and 10 high, each mine resting on its base, with a total weight of high explosives of 250,000 pounds.

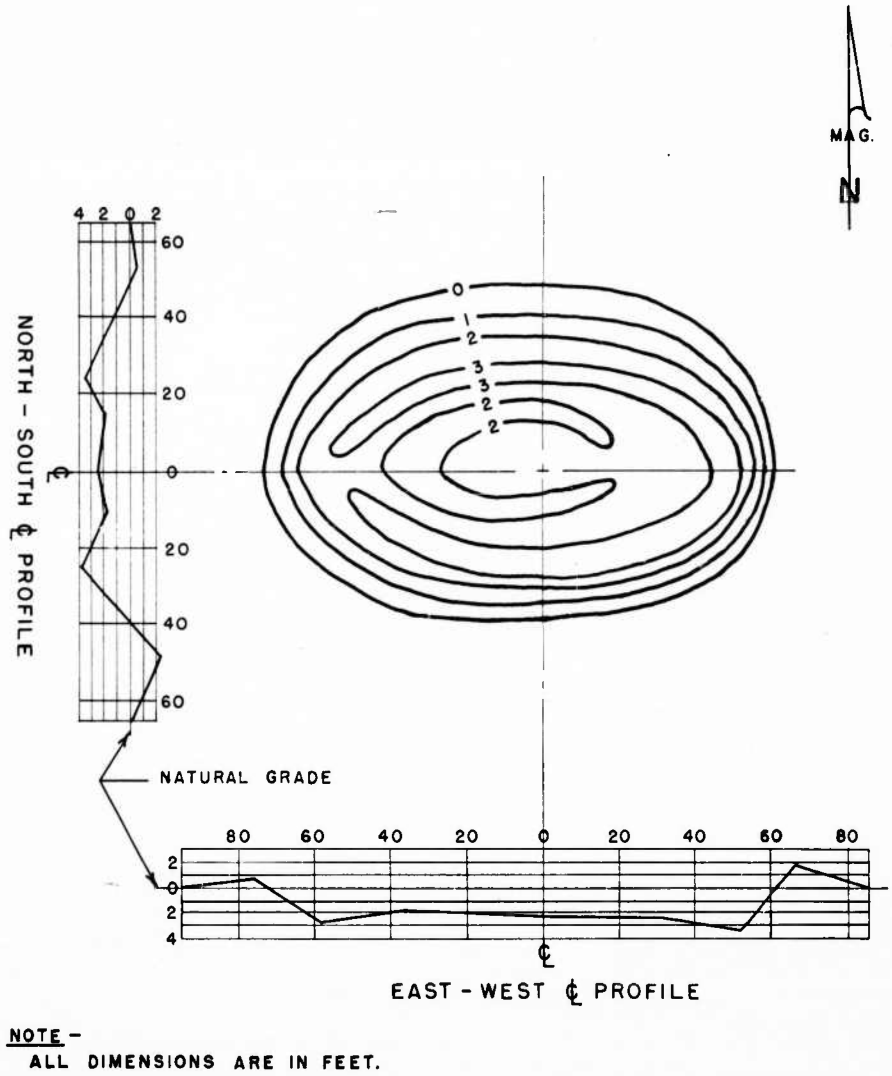


FIGURE 99a. Crater plan and profiles, Test 7.

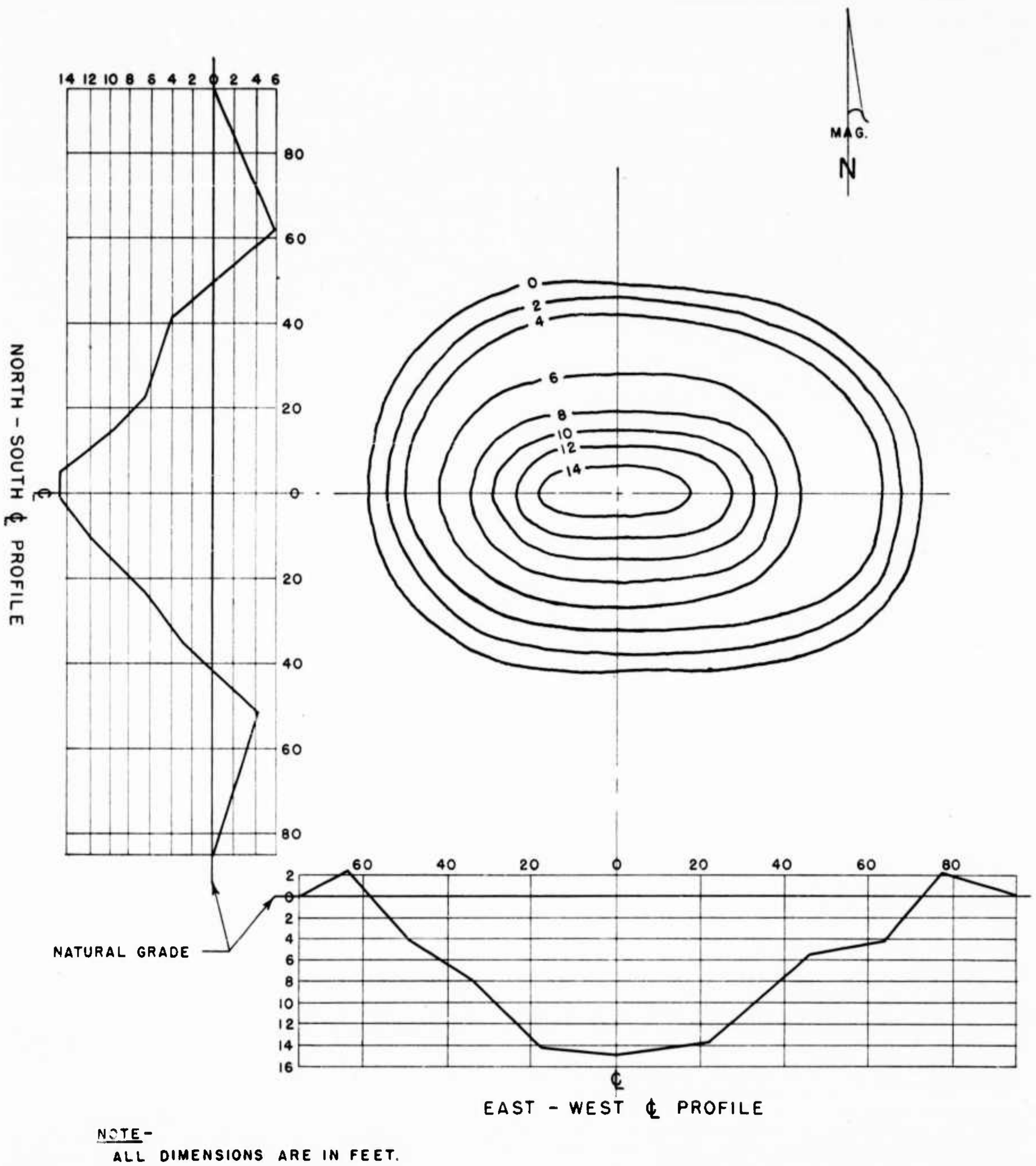


FIGURE 99b. Crater plan and profiles, Test 8.

4. Priming

Stack 2 was primed using Composition C–2 and primacord in the same manner as in previous tests. Approximately 10 percent of the mines in the top outer row of the stack were primed in the fuze cup with Composition C–2 and primacord. A single primacord lead passed completely around the stack connecting all primed mines and joining back onto itself. Three Engineer Special electric blasting caps were connected to the primacord at this junction and the caps were connected to the firing circuit in parallel.

5. Description of test and summary of results

a. General.—Stack 2 was exploded at approximately 1400 on 31 October 1945. The explosion of the 250,000 pounds of TNT in Stack 2 produced a huge ball of bright red flame which rose in the typical mushroom shape with a boiling crest of smoke and flame above a column of smoke.

b. Motion picture record.—Not recorded.

c. Air blast pressure.—Not recorded.

d. Crater data.—The explosion of the contents of Stack 2 produced a crater approximately the same size but deeper than that from the explosion of Stack 1 in Test 7. The crater was 130 feet long and 94 feet wide with an apparent depth of 14.9 feet and a true depth of 18.4 feet. Contours and profile of the crater along the longitudinal and transverse axes of Stack 2 are shown in figure 99b.

e. Ground movement.—Not recorded.

f. Effect of blast on targets.—Not recorded.

g. Damage to barracks and glass breakage.—Not recorded.

h. Missiles and fragmentation.—Not recorded.

i. Seismological data.—Not recorded.

j. Meteorological data.—Not recorded.

FIGURE 100a. Typical igloo explosion, 1st stage.

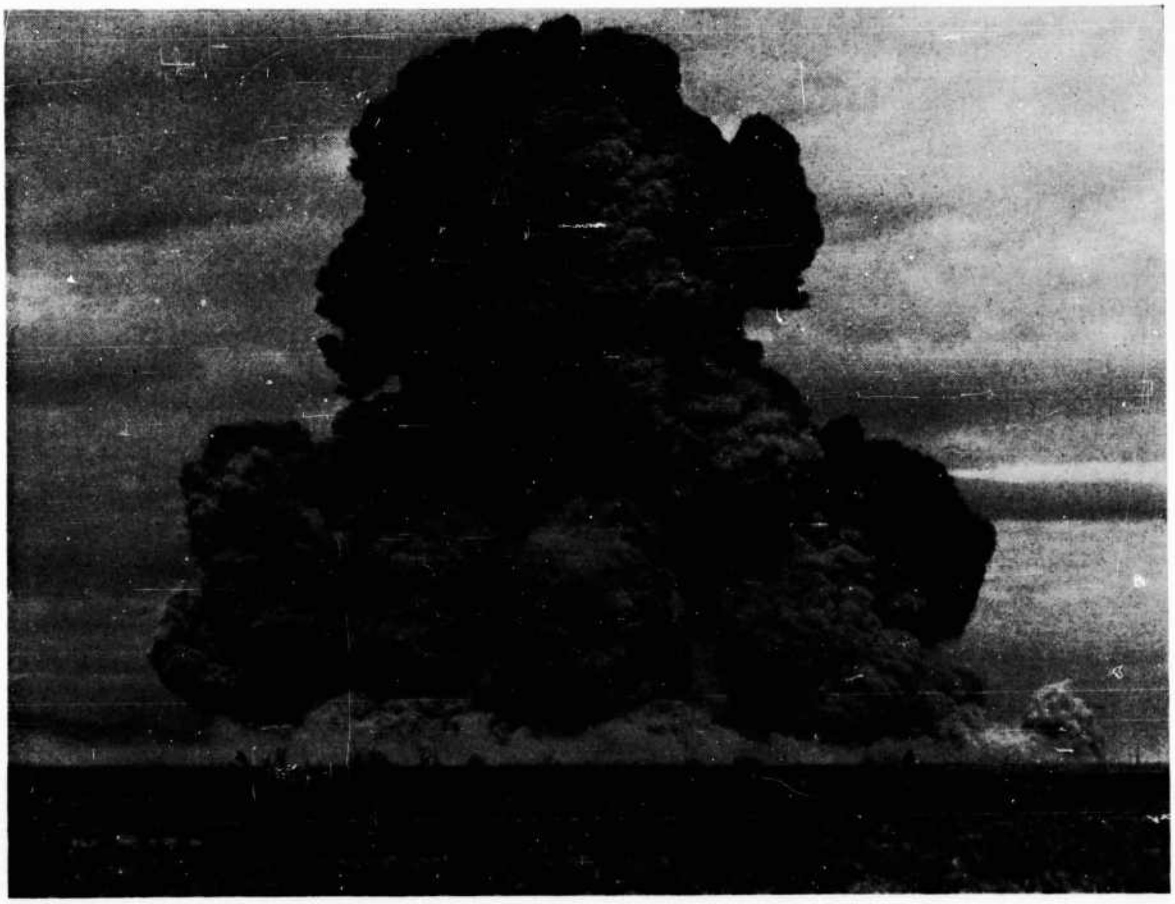


FIGURE 100b. Typical igloo explosion, 2d stage.

PART III. SUMMARY AND DISCUSSION OF RESULTS

A.—APPEARANCE OF EXPLOSIONS

1. Observations and comparisons of the pictures taken of igloo and open pile explosions show that there is a marked difference in the appearance of each type of explosion.

2. The *igloo* explosions of Tests 1, 3, and 5 produced an initial flash and then streamers of smoke that shot out at angles above 30° from the horizontal, forming a bush-like cloud that engulfed the flames within (figs. 100a and 100b). This cloud merged with the dust near the ground and developed into a billowing black mass of smoke which rose to a height of 2,380 feet within 2 minutes in Test 1.

3. The *open pile* explosions of Tests 2, 4, 6, 7, and 8 produced much more flame than the igloo explosions and the flame was visible in the cloud which boiled up into a mushroom-shaped crest of smoke and flame above a column of smoke (figs. 101a and 101b).

4. The flames observed were bright yellow and red in the explosions involving TNT and Amatol and a deeper red in the explosions of Torpex.

5. In most of the tests two reports were heard. The second report was assumed by some observers to be a reflection from the overhanging clouds. The same phenomenon, however, occurred in explosions on cloudless days, and since these double reports are quite often reported they appear to be a characteristic of explosions caused by a double peak which appears in the blast curve.

B.—MOTION PICTURE RECORD

1. Motion pictures were taken of the explosions of Tests 1 to 6, inclusive, at normal film speed, but no motion pictures were obtained of Tests 7 and 8. The most interesting and important pictures, however, were three high speed motion pictures which were taken during Test 1. These were—

a. Close-up of the explosion from the right front of Igloo A (Camera No. 1, fig. 2, 1,000 frames per second).

b. Close-up from the side of Igloo C (Camera No. 2, fig. 2, 1,430 frames per second).

c. Close-up from the side of Igloo B (Camera No. 3, fig. 2, 1,430 frames per second).

2. Selected frames from the pictures obtained with Camera No. 1, figures 102a to 102n, inclusive, show the following sequence of events:

a. Flames appear at the front of igloo and apparently the front has been blown out.

b. Flames appear at the rear of the igloo and apparently the rear has blown out.

c. The roof and side walls give way and a boiling flame and smoke cloud forms and begins to rise and spread.

3. Selected frames from the pictures obtained with Camera No. 2, figures 103a to 103l, inclusive, reveal some of the phenomena of explosions which are seldom seen but which may be explained as follows:

a. When a charge is detonated above ground a shock wave will spread out almost spherically. As this shock wave, called the incident wave, strikes the ground it is reflected. At some distance from the explosion these two waves intersect and a new reflection called a "mach" wave is set up. This wave grows and ultimately absorbs the incident and reflected waves, resulting in only one apparent shock wave.

b. In these pictures it is believed that the wave having the form of a sector of a circle is a reflected wave, and that the "snub nose" of the wave front is a mach wave.

c. The complete motion picture film from this camera (No. 2) shows that the air shock wave from an explosion apparently causes the major damage. It appears as a hemispherical mass of dense air moving outward from the explosion at a speed es-

FIGURE 101a. Typical open pile explosion, 1st stage.

FIGURE 101b. Typical open pile explosion, 2d stage.

timated at 2,000 feet per second at 200 feet. A positive and suction phase of this wave occurs before the missiles and smoke cloud arrive at any point. This is shown in the high-speed photography that slows down the "split-second" action of the shock wave until the wave apparently flows slowly over smooth objects and then recedes much as a wave on the beach.

4. Selected frames from the pictures obtained with Camera No. 3, figures 104a to 104j, inclusive, also show the reflected wave and mach wave. At 0.0028 second after the shock wave reaches Igloo B (fig. 104c) two shock waves appear and pass up the rear of the Igloo finally merging into one wave at 0.0056 second. A possible explanation of this phenomenon is that two waves were initiated, one

FIGURE 102a. The explosion has occurred in the primary igloo A but its effect has not become visible. Elapsed time between this and subsequent pictures is given with each picture.

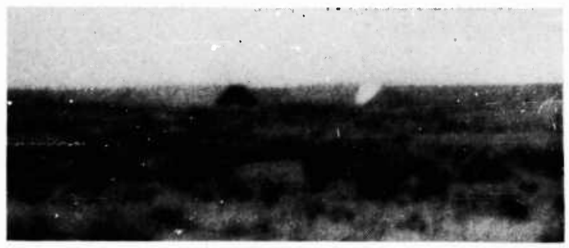


FIGURE 102b. 0.0010 second. The explosion has blown out the front of the primary igloo.

FIGURE 102c. 0.0020 second. The rear of the igloo has been blown out.

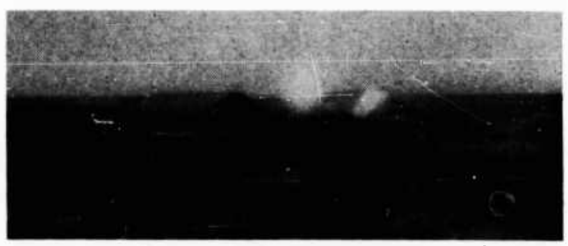


FIGURE 102d. 0.0030 second.

FIGURE 102e. 0.0050 second.

FIGURE 102f. 0.0060 second.

FIGURE 102g. 0.0070 second. The roof of the igloo is beginning to blow out.

FIGURE 102h. 0.0080 second.

FIGURE 102i. 0.0100 second.

FIGURE 102j. 0.0120 second.

FIGURE 102k. 0.0150 second.

FIGURE 102l. 0.0240 second.

FIGURE 102m. 0.0280 second.

FIGURE 102n. 0.0290 second.

FIGURE 103a. The shock wave has not yet reached the Navy type igloo C. Elapsed time between this and subsequent pictures is given with each picture.

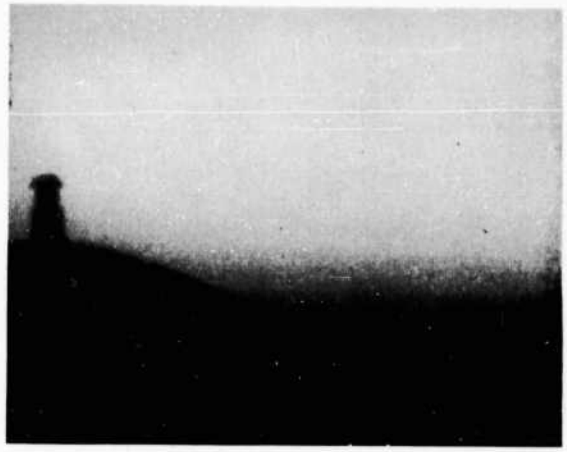


FIGURE 103b. 0.0014 second. The wave front has reached the igloo and the dense air behind it has refracted some sunlight onto the igloo.

FIGURE 103c. 0.0028 second.

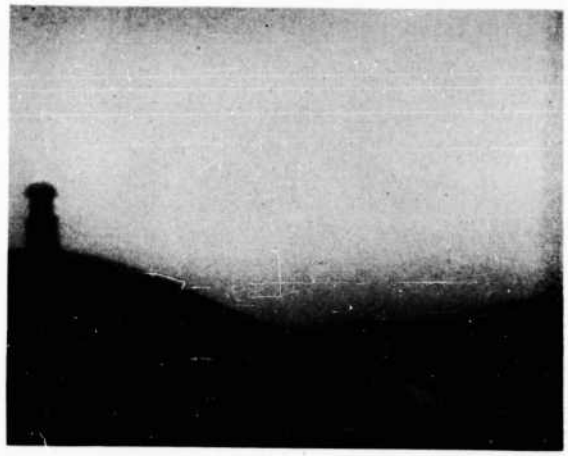


FIGURE 103d. 0.0042 second. The wave front is now clearly visible.

FIGURE 103e. 0.0056 second.

FIGURE 103f. 0.0070 second.

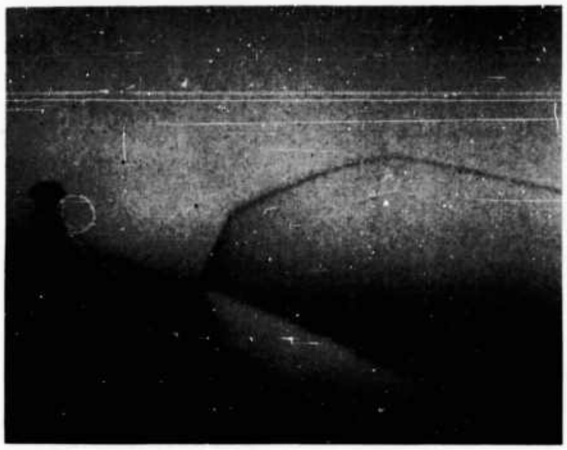


Figure 103g. 0.0085 second.

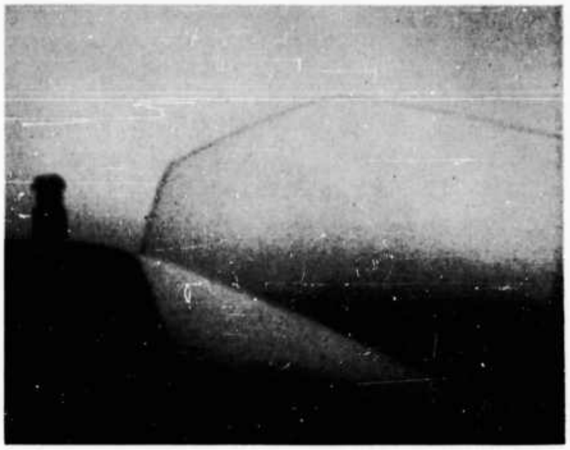


Figure 103h. 0.0100 second.

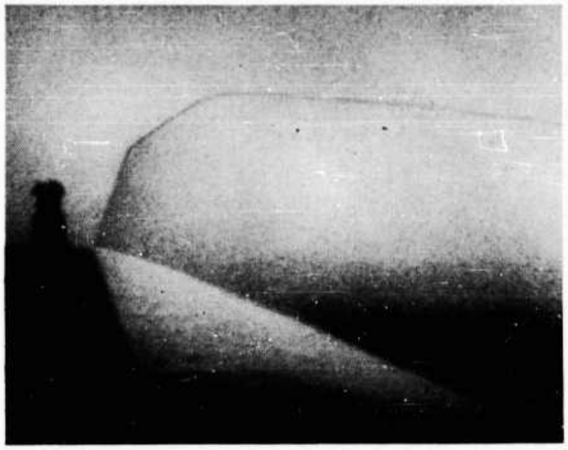


Figure 103i. 0.0127 second.

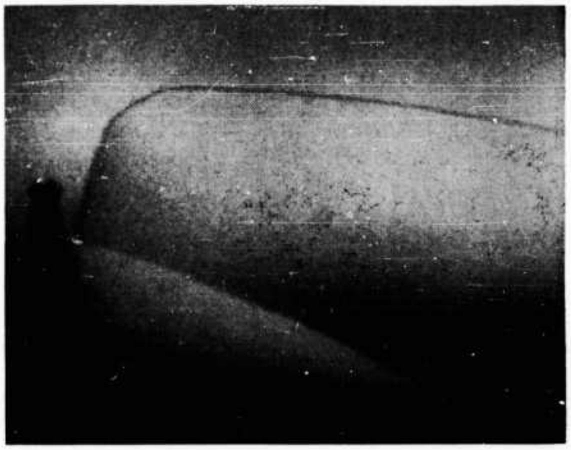


Figure 103j. 0.0141 second.

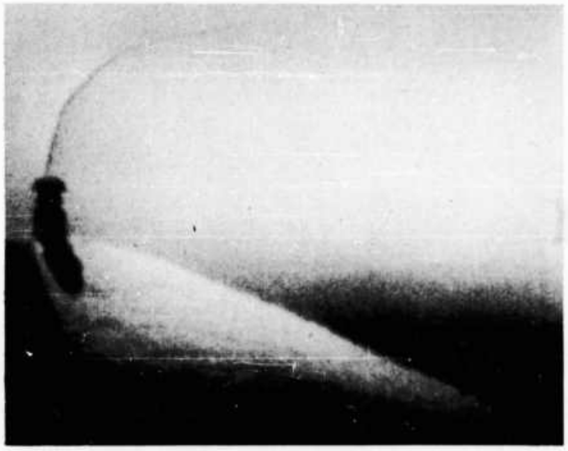


Figure 103k. 0.0155 second.

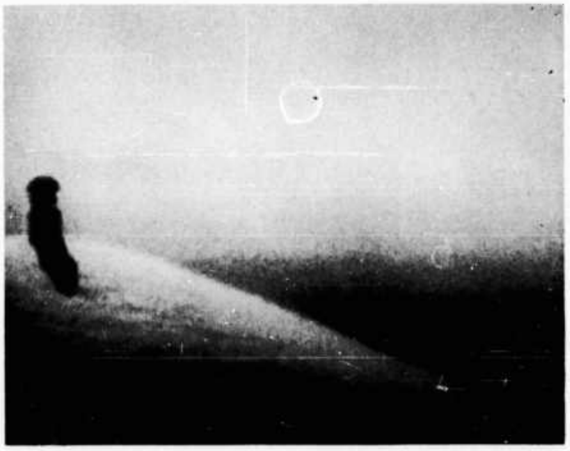


Figure 103l. 0.0169 second.

from the front and one from the rear of the exploding igloo. In support of this explanation it is noted that the close-up of the explosion of Igloo A (figs. 102b and 102c) shows that the time interval between the burst of the flame from the front end and from the rear end is approximately 0.001 second. The two shock waves appear about 2 feet apart in the pictures from Camera 3 and since the velocity of the shock wave is of the magnitude of 2,000 feet per second, the time interval between the waves would be 2/2,000 or also 0.001 second.

5. A complete film of the 1945 High Explosive Igloo Tests has been produced by incorporating the pictures of each of the tests into a single film in the proper sequence and by the addition of explanatory titles and diagrams. This film is available at the office of the ANESB in Washington, D. C.

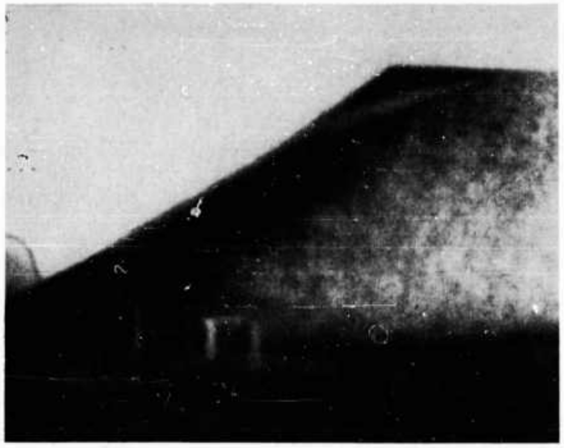


FIGURE 104a. The shock wave has reached the Army-type Igloo B and has just become visible at the left hand edge of the picture. Elapsed time between this and subsequent pictures is given with each picture.

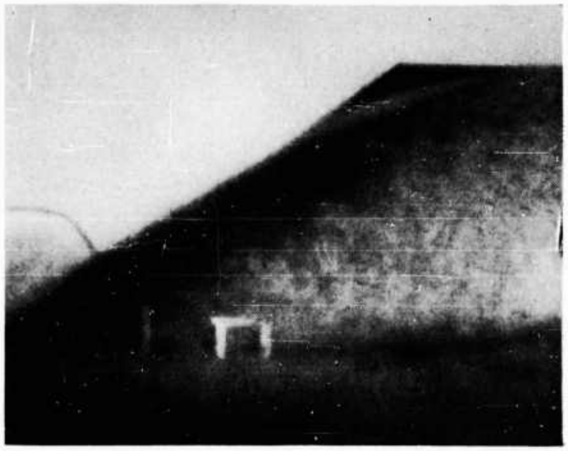


FIGURE 104b. 0.0014 second.

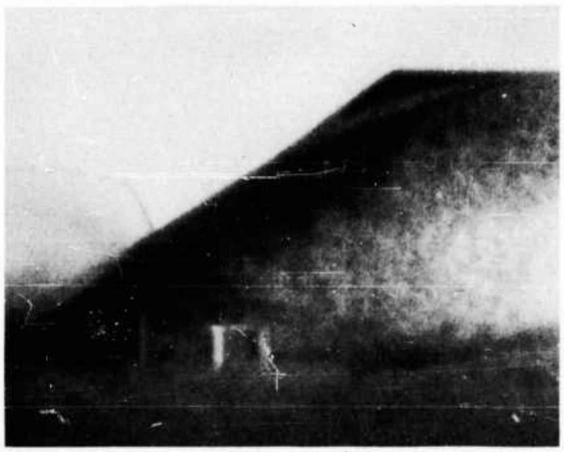


FIGURE 104c. 0.0028 second.

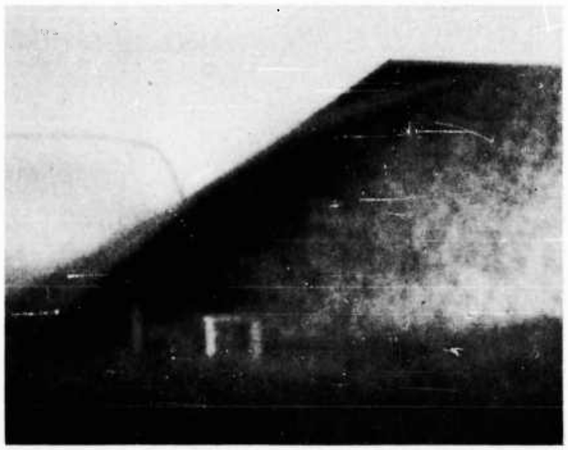


Figure 104d. 0.0042 second. Sunlight is refracted by the relatively dense air behind the wave front, and is directed downward onto the igloo.

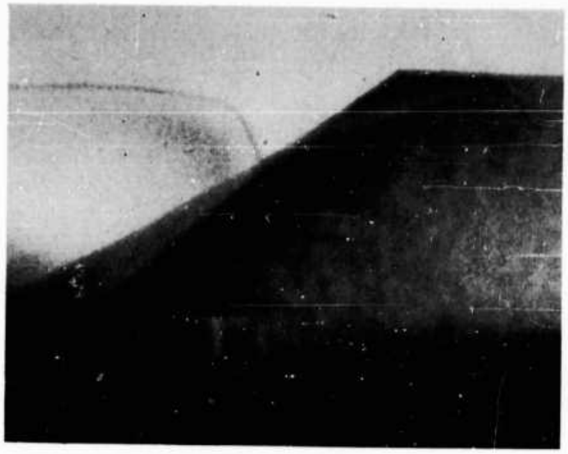


FIGURE 104e. 0.0056 second.

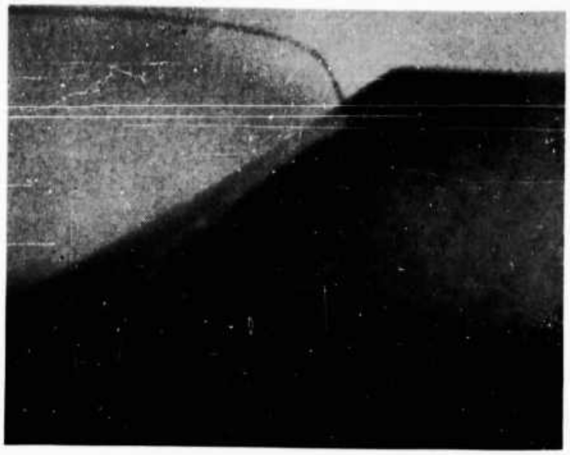


FIGURE 104f. 0.0070 second.

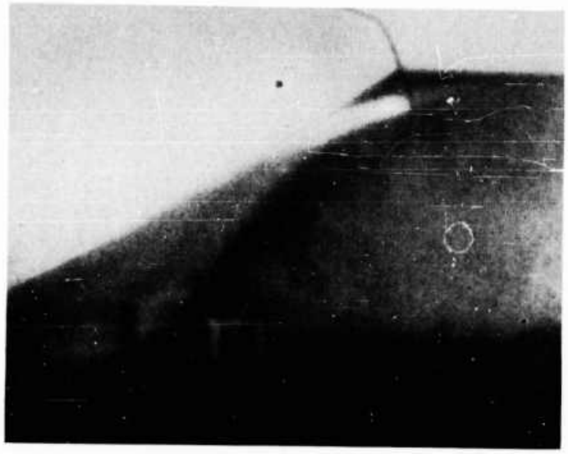


FIGURE 104g. 0.0085 second.

FIGURE 104h. 0.0100 second.

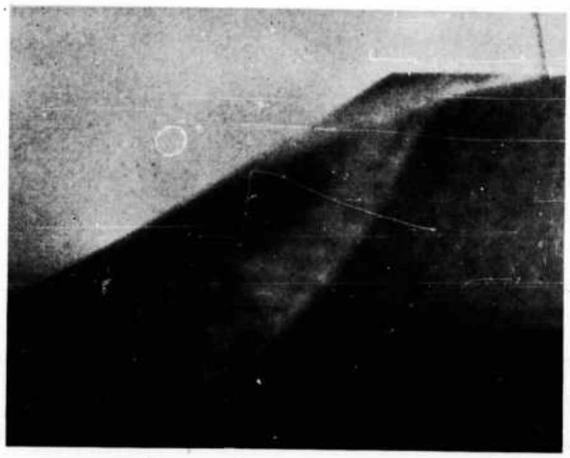


FIGURE 104i. 0.0113 second.

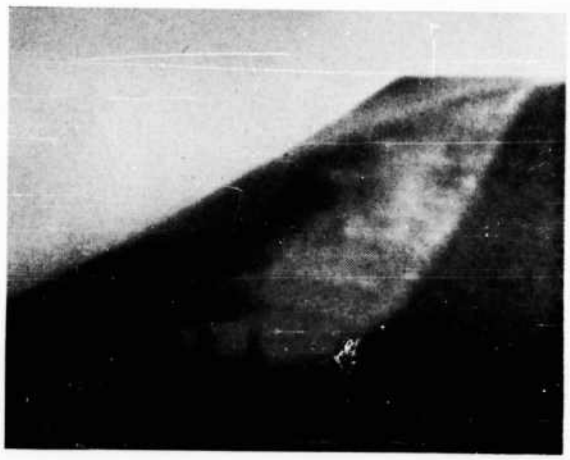


FIGURE 104j. 0.0127 second. The wave front is moving horizontally at more than 2,900 feet per second.

C.—AIR BLAST PRESSURES

1. The most complete arrangements for the measuring and recording of blast pressures were those made for Test 1. In subsequent tests (2, 3, and 4) only paper meters were used.

2. The results obtained in Test 1, up to a distance of approximately 450 feet from the center of the explosion, were disappointing because of the extreme scatter of the data, the unsuitability of some of the gages and meters, and too high an estimation of the probable peak pressures. No attempt has, therefore, been made to fit a smooth curve to these data but table XVII has been prepared to show the values obtained from all the different types of gages and meters which were used.

3. A study of these data indicates that—

a. The Princeton box gages probably gave the most reliable results within the 230 foot zone. These were 43 pounds per square inch at 185 feet and 32 pounds per square inch at 230 feet. The higher pressures given by the ball crusher gages are considered unreliable because this gage is not very suitable for the measurement of pressures within this range. Difficulties were encountered in operating the piston and T. M. B. gages and there is doubt that they recorded the true pressures accurately.

b. Beyond the 230 foot zone the foil and paper meters gave fairly uniform and consistent results which are believed to be reasonably accurate.

TABLE XVII.—*Peak blast pressures (pounds per sq. in.), all meters, Test 1*

[Figs. 20a, 20b, 20c]

Distance, feet	Paper meters			Foil meters	Princeton box gages	Piston gages	Ballcrusher gages	T. M. B. gages
	Near igloos	North line	West line					
145							96	
							122	
185					43		0	
							79	
200						0		
						0		
						28. 9		
						29. 9		
207								0
								15. 3
								11. 7
230					<32	0		
						0		
234	*12. 6							
	**7. 7							
	**7. 7							
	*7. 7							
240	*12. 6							
	**7. 7							
	*7. 7							
	*7. 7							
246	*12. 6							
	*7. 7							
	**7. 7							
	*12. 6							
247								0
252	*12. 6							
	*12. 6							
	*12. 6							
	*7. 7							

*Blown apart.
**Blown down

TABLE XVII.—*Peak blast pressures (pounds per sq. in.), all meters, Test 1*—Continued

Distance, feet	Paper meters			Foil meters	Princeton box gages	Piston gages	Ball crusher gages	T. M. B. gages
	Near igloos	North line	West line					
270				11. 5				
280						24. 6		
						17. 5		
287								0
296	**7. 7							
	**1. 2							
	**1. 8							
	**2. 7							
302	**3. 6							
	**2. 7							
	**2. 7							
	**3. 6							
308	**5. 8							
	**3. 6							
	**3. 6							
	**3. 6							
314	**3. 6							
	**3. 6							
	**3. 6							
	**3. 6							
315				10. 5				
				5. 09				
327								0
354				7. 35				
360						0		
						0		
						0		
367								0
407								0
450				10. 5				
462		5. 8	7. 7					
475				8. 42				
488		3. 6	7. 7					
500				7. 35				
510				7. 35				
517		3. 6	5. 8					
520						<5. 5		
538				7. 35				
540				6. 18				
548		3. 6	7. 7					
580				7. 35				
582		3. 6	7. 7					
615		3. 6	7. 7					
620				3. 96				
640				3. 96				
650		2. 7	5. 8					
670				3. 96				
691		3. 6	5. 8					
700						0		
						1. 05		
720				2. 97				
731		2. 7	3. 6					
770				2. 97				
775		2. 7	3. 6					

*Blown apart.
**Blown down.

TABLE XVII.—*Peak blast pressures (pounds per sq. in.), all meters, Test 1*—Continued

Distance, feet	Paper meters			Foil meters	Princeton box gages	Piston gages	Ball crusher gages	T. M. B. gages
	Near igloos	North line	West line					
800						0		
						1.53		
						0		
820		2.7	3.6	2.97				
868		2.7	2.7					
870				2.97				
920				2.97				
924		2.7	2.7					
970				2.97				
975		2.7	2.7					
1,020				0				
1,030		1.8	2.7					
1,070				2.10				
1,100		1.2	2.7					
1,120				3.96				
1,160		1.2	1.8					
1,170				2.97				
1,220				0				
1,230		1.2	1.8					
1,270				2.10				
1,300		.8	1.8			0		
						0		
1,370		.8	1.8					
1,460		.8	1.8					
1,550		.8	1.2					
1,640		.8	1.2					
1,740		.8	1.2					
1,750						1.0		
1,840		.8	.8					
1,940		.6	.8					
2,060		.6	.8					
2,180		.6	.6					
2,310		.6	.6					
2,450		.4	.6					
2,600		.4	.6					
2,740		0	.6					
2,900		0	.4					
3,080		0	0					
3,270		0	.4					
3,460		0	.4					
3,660		0	.4					
3,880		0	.4					
4,120		0	0					
4,350		0	0					

c. In general the pressures recorded during this test were much less than anticipated from a study of the data obtained from smaller explosions, as set forth in Reference 8.

4. The use of paper meters in Tests 1, 2, 3, and 4 and the fairly uniform and consistent results obtained with them permit of direct comparisons between explosions in igloos and in open piles; explosions of 125,000 and 250,000 pounds of explosives; and explosions of 50/50 Amatol and Torpex. The pressures obtained with the paper meters in Tests 1, 2, 3, and 4 have, therefore, been recorded in table XVIII, and the following conclusions have been drawn from them:

a. For equal amounts of explosives of the same kind (Tests 1 and 4) the pressures from an explosion in an open pile revetment are somewhat greater than the pressures from an explosion in an igloo. This probably is due to the confining effect of the igloo concrete and earth cover.

b. The differences between the pressures generated by the explosion of 125,000 pounds of Amatol in an open revetment (Test 2) and 250,000 pounds of Amatol in an open revetment (Test 4) are not as pronounced as one would expect, but the pressures from the 125,000 pound explosion decrease with distance at a rapid rate.

c. Torpex gave greater pressures than equal amounts of Amatol to a distance of approximately 3,500 feet from the explosion as shown by a comparison of the pressures recorded in Tests 1 and 3.

d. The pressures off the sides (west meter lines) of the igloos and open piles are greater than the pressures off the front (north meter lines).

TABLE XVIII.—*Peak blast pressures (pounds per sq. in.) paper meters, Tests 1, 2, 3, 4*

[Figs. 20a, 20b, 67, 75, 89]

Distance feet	Near igloos	Test 1		Test 2		Test 3		Test 4	
		North	West	North	West	North	West	North	West
234	*12.6								
	**7.7								
	**7.7								
	*7.7								
240	*12.6								
	**7.7								
	*7.7								
	*7.7								
246	*12.6								
	*7.7								
	**7.7								
	*12.6								
247					12.6				
252	*12.6								
	*12.6								
	*12.6								
	*7.7								
273					12.6				
296	**7.7								
	**1.2								
	**1.8								
	**2.7								
302	**3.6				7.7				
	**2.7								
	**2.7								
	**3.6								
308	**5.8								
	**3.6								
	**3.6								
	**3.6								
314	**3.6								
	**3.6								
	**3.6								
	**3.6								
330					12.6				
367					7.7				
400					7.7				
435					5.8				
457				5.8					
462		5.8	7.7			7.7	12.6	7.7	7.7
473				5.8					

*Blown apart.
**Blown down.

TABLE XVIII.—*Peak blast pressure (pounds per sq. in.) paper meters, Tests 1, 2, 3, 4*—Continued

[Figs. 20a, 20b, 67, 75, 89]

Distance feet	Near igloos	Test 1		Test 2		Test 3		Test 4	
		North	West	North	West	North	West	North	West
476					7. 7				
488		3. 6	7. 7			12. 6	7. 7	5. 8	7. 7
507				5. 8					
516					5. 8				
517		3. 6	5. 8			7. 7	7. 7	5. 8	7. 7
533				3. 6					
548		3. 6	7. 7			7. 7	7. 7	5. 8	7. 7
560					3. 6				
568				5. 8					
582		3. 6	7. 7			7. 7	7. 7	7. 7	7. 7
598				3. 6					
605					5. 8				
615		3. 6	7. 7			7. 7	7. 7	7. 7	7. 7
631				3. 6					
650		2. 7	5. 8			5. 8	7. 7	5. 8	7. 7
653					5. 8				
671				3. 6					
691		3. 6	5. 8			5. 8	5. 8	3. 6	5. 8
706					3. 6				
710				3. 6					
731		2. 7	3. 6			7. 7	7. 7	2. 7	3. 6
751				3. 6					
760					3. 6				
775		2. 7	3. 6			5. 8	7. 7	3. 6	3. 6
795				2. 7					
815					5. 8				
820		2. 7	3. 6			5. 8	5. 8	3. 6	3. 6
842				3. 6					
868		2. 7	2. 7			3. 6	7. 7	3. 6	3. 6
885					2. 7				
894				2. 7					
921		2. 7	2. 7			3. 6	5. 8	3. 6	2. 7
945					2. 7				
946				2. 7					
975		2. 7	2. 7			3. 6	3. 6	2. 7	3. 6
1,000				2. 7					
1,015					2. 7				
1,030		1. 8	2. 7			2. 7	3. 6	1. 8	2. 7
1,070				2. 7					
1,085					2. 7				
1,100		1. 2	2. 7			1. 8	3. 6	2. 7	2. 7
1,130				1. 8					
1,155					2. 7				
1,160		1. 2	1. 8			1. 8	2. 7	1. 8	3. 6
1,190				1. 8					
1,230		1. 2	1. 8			1. 8	2. 7	1. 8	3. 6
1,245					1. 8				
1,260				1. 8					
1,300		. 8	1. 8			2. 7	3. 6	1. 2	1. 8
1,330				1. 8					
1,335					1. 8				
1,370		. 8	1. 8			2. 7	2. 7	1. 2	3. 6
1,420				1. 2					
1,425					1. 8				
1,460		. 8	1. 8			2. 7	2. 7	1. 2	1. 2

TABLE XVIII.—*Peak blast pressure (pounds per sq. in.) paper meters, Tests 1, 2, 3, 4*—Continued

[Figs. 20a, 20b, 67, 75, 89]

Distance feet	Near igloos	Test 1		Test 2		Test 3		Test 4	
		North	West	North	West	North	West	North	West
1,500				1.8					
1,525					.8				
1,550		.8	1.2			1.2	2.7	.8	1.8
1,590				1.2					
1,625					1.2				
1,640		.8	1.2			1.2	2.7	1.2	1.8
1,690				1.2					
1,725					.8				
1,740		.8	1.2			1.2	2.7	.8	1.2
1,790				1.2					
1,840		.8	.8			1.2	1.8	.8	.8
1,845					.8				
1,880				.8					
1,940		.6	.8			1.2	1.8	.6	1.2
1,965					.8				
2,000				.8					
2,060		.6	.8			1.2	1.8	.6	1.8
2,095					.8				
2,120				.8					
2,180		.6	.6			1.2	1.8	.8	1.2
2,235					.8				
2,240				.4					
2,310		.6	.6			.8	1.2	.6	.8
2,380				.6					
2,385					.4				
2,450		.4	.6			1.2	1.2	.6	.8
2,525					.8				
2,550				.8					
2,600		.4	.6			.8	1.2	.6	.8
2,660				.6					
2,685					.6				
2,740		0	.6			.8	1.2	.4	.8
2,820				.6					
2,865					0				
2,900		0	.4			.8	.8	.6	.4
3,040				.4					
3,055					0				
3,080		0	0			.6	.4	.4	.6
3,228				.6					
3,245					0				
3,270		0	.4			.6	.6	0	.6
3,416				0					
3,445					0				
3,460		0	.4			.4	.4	0	.6
3,514				0					
3,660		0	.4			.4	.6	0	.6
3,665					0				
3,832				0					
3,880		0	.4			0	0	0	0
3,905					0				
4,070				0					
4,120		0	0			0	0	0	.4
4,135					0				
4,300				.4					
4,350		0	0			0	0	0	.4

e. The Navy-type door barricade in Test 1 had an effect on the pressures off the front of an igloo as shown by the range of pressures off the fronts (north meter lines) of Igloos A (with door barricade) and C (without door barricade).

f. Test 3, 250,000 pounds of Torpex in Igloo C, gave the greatest pressures; Test 4, 250,000 pounds of Amatol in an open pile revetment, gave the next largest pressures; and Test 1, 250,000 pounds of Amatol in Igloo A gave the lowest pressures for the 250,000 pound explosions.

D.—CRATER DATA

All of the crater data recorded during these tests have been assembled in table XIX. A study of these data does not reveal any unusual results. The craters formed by the explosions in Igloos C and B (Tests 3 and 5), each of which contained 250,000 pounds of Torpex, vary greatly in depth but this is believed to be due to the much stronger floor construction of the Army Igloo (B). The craters resulting from the two identical revetment explosions (Tests 2 and 6, 125,000 pounds Amatol) are quite comparable and the craters from the open pile explosions agree quite well except as to depth. The very shallow depth of the crater formed in Test 7 is largely due to the fact that the explosives in the center of the pile were bulk explosives packed in wooden boxes or light containers. The diameters and lengths of the craters resulting from igloo explosions are greater than those resulting from revetment and open pile explosions, probably because of the presence of the concrete and earth cover. All of the craters were oval or circular in shape but the piles of explosives which were detonated were relatively long and narrow (for igloos, approximately 26′ wide x 80′ long). As has been noted in previous paragraphs, the pressures off the sides of these relatively long and narrow piles are usually greater than off the ends, and this is emphasized by these crater dimensions. Generally the length of the craters is approximately twice the lengths of the piles of explosives but from 3 to 6 times the widths.

TABLE XIX.—*Crater data—all tests**

Test No.	Explosives		Type of storage	Crater dimensions (in feet)			
	Kind	Quantity lbs.		Length	Width	Apparent depth	Actual depth
1	50/50 Amatol	250, 000	Igloo	200	150	8	13. 9
2	do	125, 000	Revetment	75	77	6	10
3	Torpex	250, 000	Igloo	154	110	18. 2	
5	do	250, 000	do	151	125	10. 7	
6	50/50 Amatol	125, 000	Revetment	87	77	10. 3	
7	TNT, Amatol, etc	250, 000	Open pile	130	85	3. 75	
8	TNT	250, 000	do	130	90	15	18. 4

*No data were recorded for Test 4 as this test was made on the site of the crater from Test 1 (Igloo A) which had been filled, compacted, and levelled.

E.—GROUND MOVEMENTS

1. Measurements of ground movements, horizontal and vertical, outside the crater ring were made in Tests 1, 2, and 4. These are assembled for comparison and study in table XX. Generally the movements were very small and not discernible by observation. However, the data obtained by surveys of the grids of stakes, which were placed around the igloos or revetments before the explosions, revealed that there was movement in both directions. In Test 1 movement was detected as far as Igloo D (500 feet from center of explosion) and in Test 4 static waves were formed on the surface of the ground which measured nearly 8 inches from crest to trough. It should be noted, however, that in Test 4, the explosion took place on the compacted fill of the crater formed in Test 1 (Igloo A). The ground movements encountered in these tests were very small and they were very much less than anticipated. Certainly they did not indicate severe ground shock.

2. Some further data on ground movements around the explosions were obtained by noting the displacements of the target igloos. In Test 1 the

TABLE XX.—*Permanent horizontal and vertical earth displacement*

[All dimensions in feet. Ref. Figs. 23, 69, 90]

Distance from center of unit (feet)	Test 1, Igloo A 250,000 pounds Amatol								Test 2, Rev. 1 125,000 pounds Amatol				Test 4, Rev. 3 250,000 pounds Amatol					
	West (side)		East (side)		North (front)		South (rear)		North (front)		South (rear)		North (front)		South (rear)		West (side)	
	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
62.5									1.15 NE	+0.44								
65																	0.60 SW	+0.65
85	2.06 NW	+1.47																
87.5											0.40 SE	+0.14						
90			2.[illegible] NE	+1.19													.32 SW	+.37
100													0.89 NW	+0.12	0.11 SW	+0.10		
110	1.24 NW	+.61																
112.5									.29 N	+.10								
115			1.[illegible] NE	+.60			1.51 S	+1.10									.18 SW	+.08
125													.63 NW	+.07	.13 SE	+.07		
130					0	+0.09												
135	.21 W	+.2[illegible]																
137.5											.05 S	+.09						
140			.42 E	+.19			.77 S	+.12									.09 SW	+.02
150													.26 NE	−.10	.05 SE	+.03		
155					0	+.07												
160	0	+.07																
162.5									.10 N	+.02								
165				+.13			.50 S	+.17										
169.5	.22 NW	+.1[illegible]	.03 W	+.13														
175													.14 NE	−.150	0	+.03		
180					0	+.03												
185	0	+.0[illegible]																
187.5											0	+.03						
190																	0	+.03
196.4					.06 NW	+.03	.03 SW	+.05										
212.5									0	0.								
215			.04 S	0														
225															0	+.02		
237.5											0	+.03						
240																	0	+.02
275															0	+.04		
287.5											0	0						
290																	0	+.01
330					.09 NW	0												
340																	0	−.01
350															0	+.01		
375															0	−.03		

+ = Up; − = Down. Direction of displacement indicated by compass points.

head wall of Igloo C moved north (away from the explosion) ½ inch and west 1 inch with no recorded vertical movement; the head wall of Igloo B moved ½ inch south (explosion was to west) and there was no movement in Igloo D. In Test 2 the head wall of Igloo C moved ¼ inch south (explosion was to west) and vertical movements were: east head wall up $\frac{1}{16}$ inch, west wall up ⅛ inch, floor up ⅛ inch. No other target igloo movements were taken and from the meager information very few conclusions can be drawn, but apparently igloos to the side of the blast moved slightly parallel with the longitudinal axis of the explosion and an igloo to the front moved away and perpendicular to the axis of the explosion.

F.—EFFECTS OF BLAST ON TARGET IGLOOS AND REVETMENTS

1. The effects of the air blast on the target igloos and revetments was determined by observation, by slide rule gages and stop-point indicators, and by Carlson strain meters.

a. The observed effects are summarized in table XXI, and the following comments are made with respect to these data:

(1) *At 185 feet.*—The damage to igloos and revetments was not serious. In igloos it consisted principally of minor cracks in the arch, slump of the earth cover, door jamming, or doors blown off. In revetments the earth barricades slumped and were partially blown away and bombs were knocked from the piles.

(2) *At 210 to 265 feet.*—Greater damage occurred to an igloo from the explosion of 250,000 pounds of Torpex at 265 feet than from the explosion of 250,000 pounds of Amatol at 210 feet.

(3) *At 500 feet.*—There was little or no damage at this distance, but the explosion of 250,000 pounds in a revetment caused greater damage to Igloo D than 250,000 pounds in an igloo. The weakness of the Navy-type door was demonstrated here as it blew in even at 500 feet.

b. The effects of blast on the target igloos as determined by the slide rule gages and the stop-point indicators (SPI) have been described in Test 1 (Part IIA, par. 5*f*(3) and figs. 27a, 27b, and 27c).

(1) There is, in general, agreement between the final distances measured from floor to ceiling recorded on the slide gages and that obtained by field survey. These measurements are greater than the measurements taken by the SPI indicating that only a small part of the recorded differences between ceiling and floor can be accounted for by permanent set of the arch due to stress. The remainder, i. e., the difference between the SPI and the slide gage, is a measure of the final relative movement of the arch unit and the floor unit moving independently.

(2) It is noted in the above paragraph that the extreme readings of the SPI are assumed to be the final readings, whereas, the actual final measurements must be somewhat less. The assumption seems justified as a means of evaluating the limiting degree, rather than the actual magnitude, of the movement due to stress.

(3) The actual extreme movements of the arch may be greater than those recorded on the SPI due to inertia stretch of the instrument cord. Considering the degree of known independent movement of the floor and arch units, it would seem that the SPI readings are nearer to the degree of strain than those shown on the slide gages.

(4) The reading of the SPI at Point 3 of Magazine B has been disregarded because it is out of line with the other readings. It was noted on entering the magazine that the wire ventilator screen had been blown

TABLE XXI.—*Summary of observed target igloo and revetment damage*

Test no.	Explosives and unit exploded	Distance from explosion in feet		
		185	210 to 265	400 to 750
1	250,000 pounds Amatol in Igloo A.	Igloo B–Continuation of crack across the center of the arch, new crack along center of floor, earth cover slumped, door jammed, ventilator blown off.	Igloo C–Door blown in, bombs knocked down and tilted, ventilator blown off.	Igloo D (500 feet), door blown in.
2	125,000 pounds Amatol in Revetment 2.	Igloo C–Door blown off. (Other damage slight and contents undisturbed.)	No target unit	Rev. 2 (400 feet), no damage. Igloo B (500 feet), no damage. Igloo D (750 feet), no damage.
3	250,000 pounds Torpex in Igloo C.	Rev. 2—Earth barricade slumped and was partially blown away, bombs knocked off dunnage and dunnage blown away.	Igloo B—Cracks in front wall and earth cover slumped.	Igloo D (750 feet), no damage.
4	250,000 pounds Amatol in Revetment 3.	Igloo B—Door jammed, concrete spalled off top of arch at joint w/front wall exposing reinforcing rods, timbers of door barricade displaced and earth blown away.	Revetment 2—No damage.	Igloo D (500 feet), fine cracks across center of arch.
5	250,000 pounds Torpex in Igloo B.	No target unit	Rev. 2—Bombs shaken from dunnage, no other damage.	Igloo D (630 feet), no damage.
6	125,000 pounds Amatol in Revetment 2.	do	No target unit	Igloo D (840 feet), no damage.

past the cord of this instrument. The screen striking the cord of the instrument could have caused the high reading.

c. The effects of blast on the target igloos, as determined by the Carlson strain meters, have been described in Test 2 (Part IIB, par. 6*f*(2) and figs. 71 and 72a) and Test 4 (Part IID, par. 6*f*(2) and figs. 91 and 92). The data obtained are too meager to permit the drawing of sound conclusions as to the degree to which the target igloos were stressed. However, it does appear that the results obtained in Test 2 and Test 4 are fairly consistent and that the igloos were affected both by ground and air shock but that air shock was the cause of the greater stresses.

G.—DAMAGE TO BARRACKS AND GLASS BREAKAGE

1. Barracks damage

a. Prior to these tests a concrete, arch-type, earth covered igloo was considered to be barricaded, within the meaning of this term as defined in the American Table of Distances (ATD), both offensively and defensively, except at the door end when a separate door barricade was not provided. It was, therefore, the common practice to use the barricaded distances set forth in the ATD for the separation of igloos from inhabited buildings.

b. These tests proved quite conclusively that although the barracks were in no danger of collapsing they did suffer damage of a critical nature, and it is doubtful that the inhabitants thereof would have escaped serious and perhaps fatal injury from blast, flying glass, and structural damage. The barricaded distance of 2,155 feet which is prescribed by the ATD for the separation of a barricaded magazine containing 250,000 pounds of mass detonating high explosives from an inhabited building was quite inadequate in providing reasonable safety against serious injury or death and severe structural damage, so far as these earth covered igloos were concerned.

c. Although the barracks was severely stressed and weakened by Tests 1 and 2, it appears from the photographs that Torpex caused additional damage not definitely due to weakening of the structure by previous explosions.

d. As in most large explosions, glass breakage was extensive, and the dangers from flying glass were strongly emphasized by the fine splinters of glass imbedded in the walls, floors, and columns of this barracks.

H.—MISSILES AND FRAGMENTATION

Missile data which were recorded only for Test 1 have been described and discussed in Part IIA, par. 5*h*. However, observations made during all of the other tests confirmed the results of Test 1. It was especially noticeable that the complete detonations of the ammunition stored in fully loaded magazines gave quite different results from several accidental igloo explosions in which the igloos were only partially loaded and the amounts of explosives involved were less than half of those used in these tests. In these latter cases missiles in excess of 100 pounds were thrown over 5,000 feet from the door end and some pieces up to a ton were thrown as much as 1,800 feet.

I.—SEISMOLOGICAL DATA

1. Seismic records were obtained in Test 1 by the David Taylor Model Basin and in Tests 2, 3, and 4 by the U. S. Coast and Geodetic Survey. The records obtained by the David Taylor Model Basin have been discussed in Part IIA, par. 5*i*, but the records obtained by the U. S. Coast and Geodetic Survey during Tests 2, 3, and 4 have been summarized for further discussion in table XXII, and the location of the test stations for Tests 2 and 3 are shown in figure 105.

2. Calculated maximum ground displacements are arranged according to wave period and distance from the source in figure 106. The source is a 250,000 lb. explosion, though not necessarily the same one. Plotted data at 7.2 miles and 9.9 miles were taken from vibrograms of an October 1946 explosion. The data are rough and are taken from the largest waves having approximately the represented periods, which measurements are subject to considerable error. Nevertheless, the graph represents the order of displacements to expect from blasts of this size at given distances.

3. Maximum accelerations, without regard to period, are plotted in figure 107. These data were taken from measurements of the single wave at each station, which, in the judgment of the observer, was associated with the highest acceleration. The diagram shows a number of paired data. The open circles represent direct observations from an explosion of 250,000 pounds of Torpex on 19 October 1945. Inasmuch as Amatol was used in the other tests considered here, the data designated as "Amatol equivalent" were calculated on the assumption that 100 pounds of Torpex is approximately equivalent to 130 pounds of Amatol and that the rule represented in figure 108 was followed. The Era Mine datum was not so adjusted because of the small trace amplitude on the record and the consequent large allowable error.

Very little difference was noted in displacements and accelerations observed at Stations 1 and 2 which are the same distance from the source, one on overburden and the other on rock. However, the overburden was probably too shallow to influence energies contained in the observed waves which had minimum lengths of more than 700 feet. Higher frequency vibrations were probably present, but they were too feeble to be recorded by the insensitive apparatus in use. It should be noted that this station is on open prairie and the underlying ground is not the same as at the instrument

TABLE XXII.—*Summary of seismological results, Idaho Ballistic Experiment, August and October 1945, U. S. Coast and Geodetic Survey*

The observations were made under the direction of Dr. D. S. Carder, Chief of the Lake Mead Seismological Survey, using Coast and Geodetic Survey vibration meters, accelerometers, compound pendulum displacement meters, and recording apparatus; also a Benioff vibragraph. Special apparatus recorded the times of the blasts simultaneously on all of the instruments.

SUMMARY OF ACCELERATIONS AND DISPLACEMENTS

Station	Date 1945	Distance (feet)	Explosives weight (pounds)	Wave period (second)	Calculated displacement (cm.)	Calculated acceleration cm/sec.²	Remarks
1	10/18	2, 840	125, 000	0. 19	0. 0033	4. 0	Rock.
2	10/18	2, 840	125, 000	. 16	. 008	12. 5	Do.
3	10/18	5, 600	125, 000	. 27	. 0045	2. 4	Overburden.
4	10/18	9, 200	125, 000	. 37	. 0015	. 42	Do.
1	10/19	2, 840	250, 000	. 17	. 016	20	Rock.
2	10/19	2, 840	250, 000	. 17	. 015	20	Do.
3	10/19	5, 600	250, 000	. 22	. 0067	5. 5	Overburden.
3	10/19	5, 600	250, 000	. 37	. 015	4. 5	Do.
4	10/19	9, 200	250, 000	. 22	. 003	2. 5	Do.
4	10/19	9, 200	250, 000	. 48	. 008	------	Do.
5	10/19	11, 850	250, 000	. 43	. 005	1	Do.
6	10/19	21, 600	250, 000	. 65	. 0028	0. 27	Do.
x	10/30	650	300, 000	. 15	. 29	510	Do.

station which was used with the 18 August explosion. The latter station was in a river bed more than 3 miles from the site of Station 2.

4. *Accelerations versus amount of explosives used.*—This is plotted graphically in figure 108. Data obtained from direct observations were taken at a distance of 2,840 feet from the blast. Other data were taken at distances other than 2,840 feet but for purposes of comparison it was necessary to transpose these accelerations to correspond to a distance of 2,840 feet using the curve in figure 107.

The explosion of 18 August 1945 should not be used for comparison since ground and foundation conditions were not the same. Other observations form an excellent fit to the curve representing acceleration proportional to the square root of the weight of the explosives detonated.

5. *Travel times.*—Travel-time data are available for the blasts of 18 October and 19 October only. The times of the blasts were obtained when the explosions broke a relay circuit. Equipment in use at the time was designed to show accelerations and displacements. It did not give good responses to entries of ground waves. However, we believe

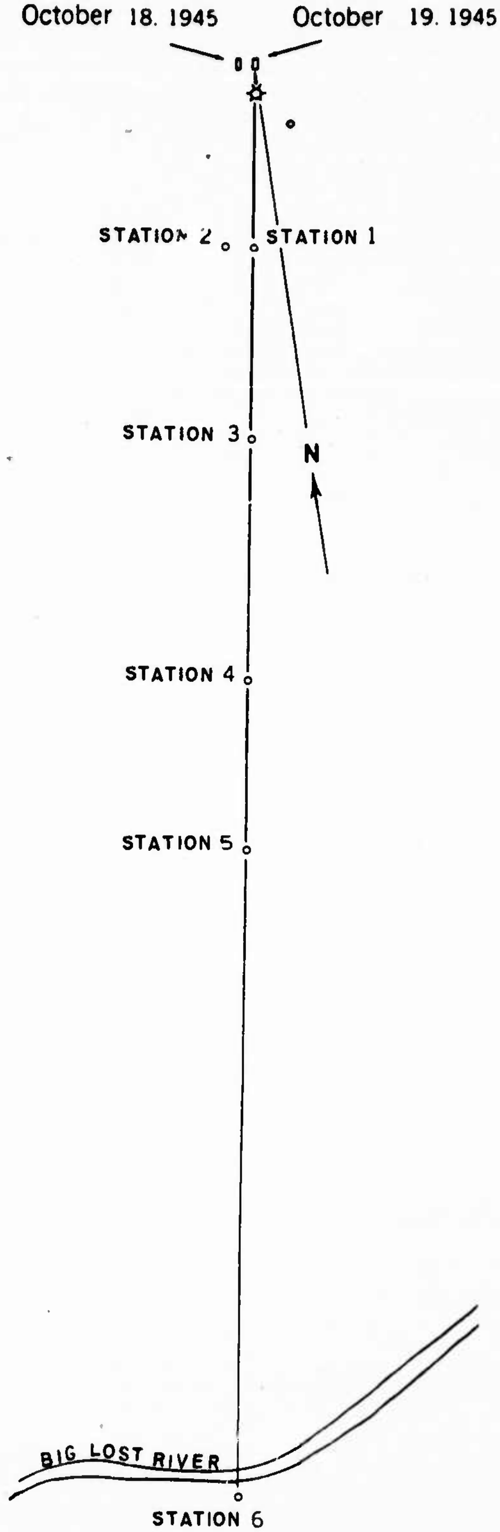


FIGURE 105. Location of stations, Tests 2 and 3.

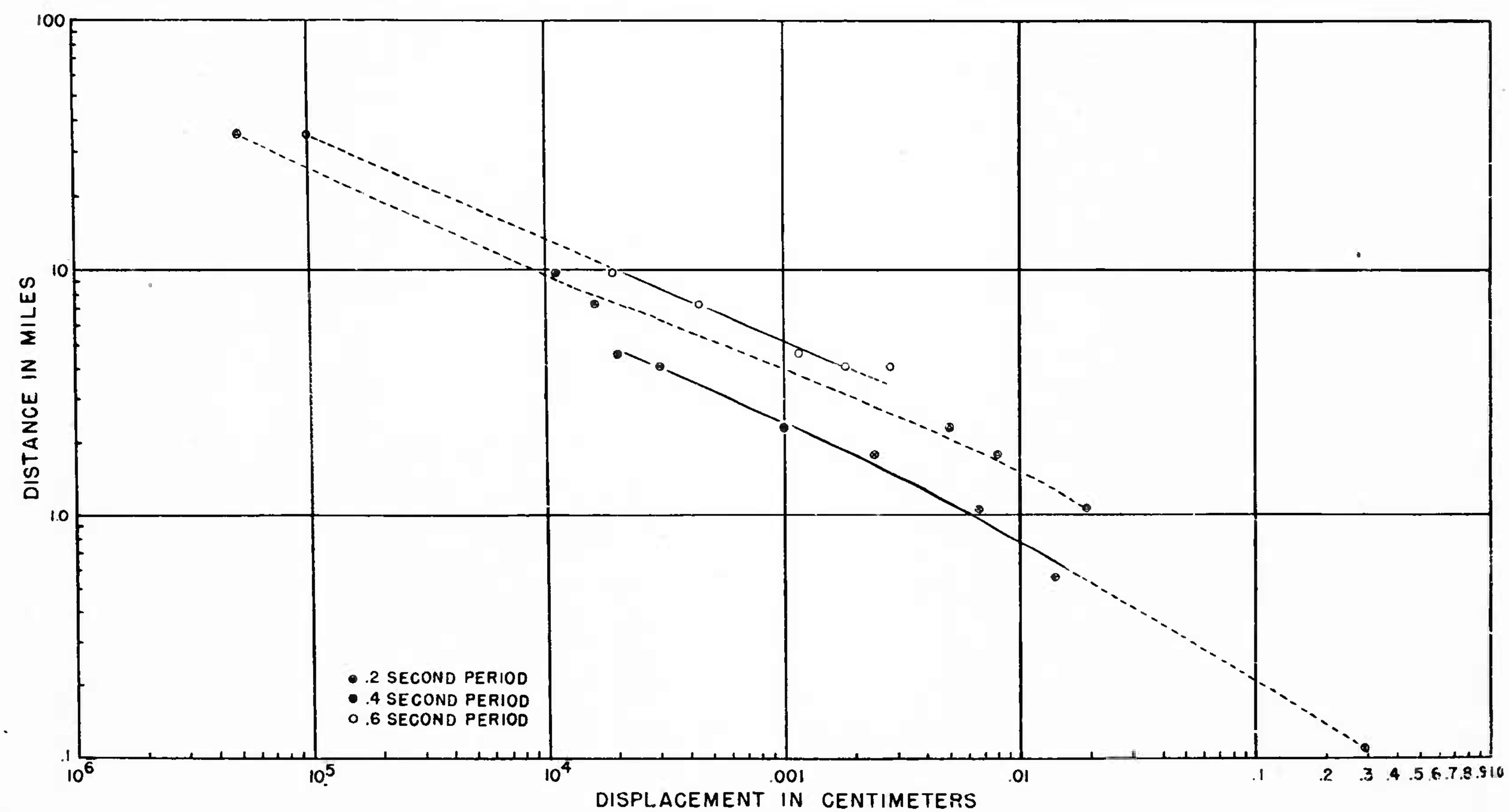
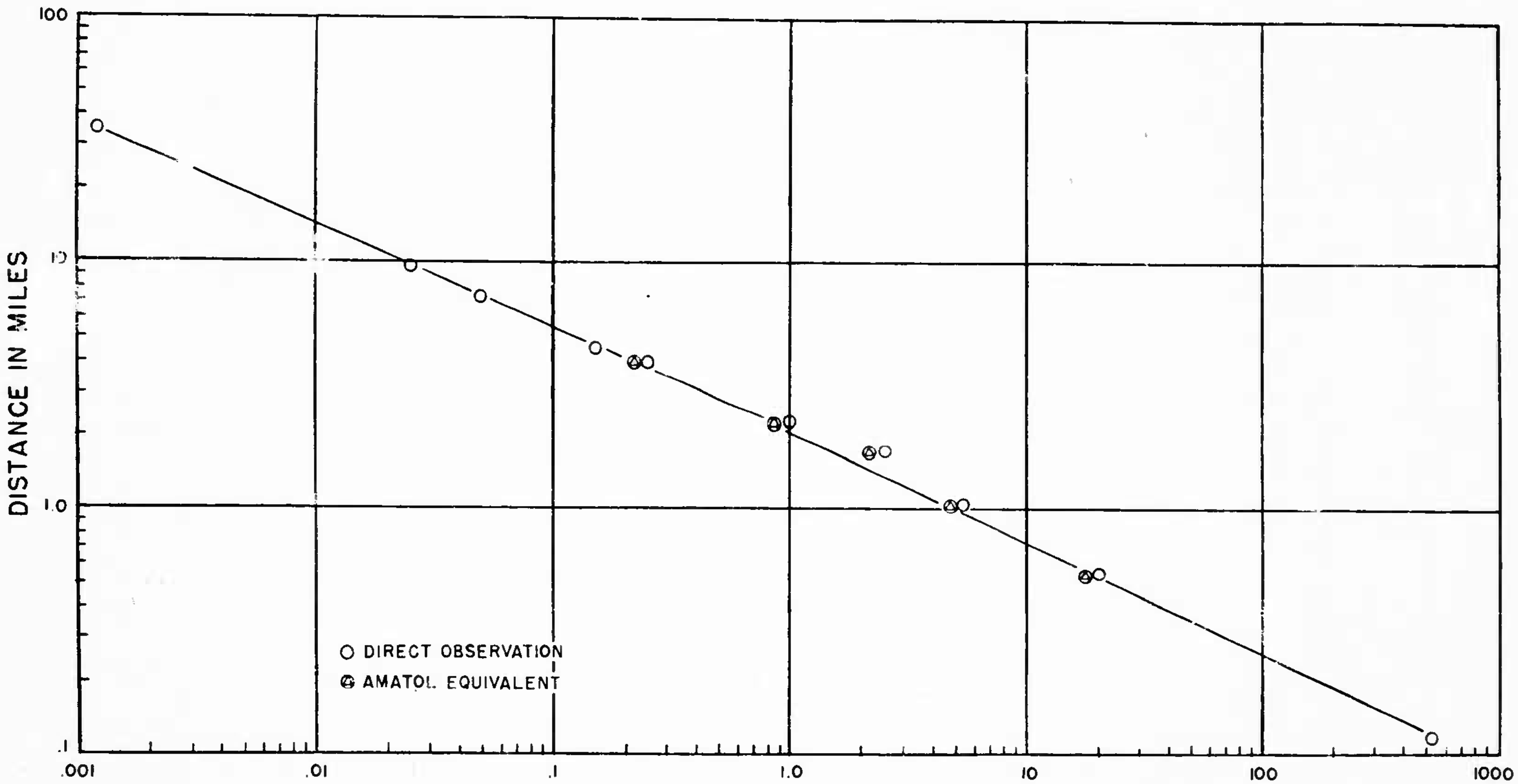


FIGURE 106. Attenuation of displacement with distance—250,000 pound explosives.



Amatol Equivalent –
100 LBS. TPX = 130 LBS. AMATOL

FIGURE 107. Maximum accelerations, without regard to period.

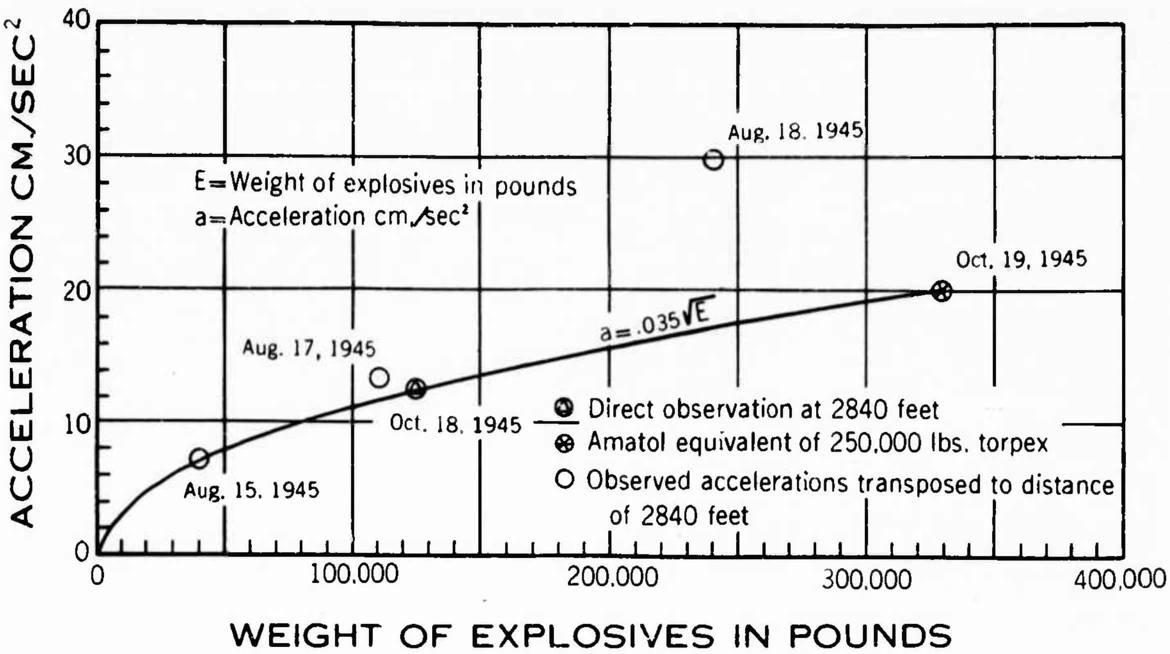


FIGURE 108. Acceleration versus amount of explosives used.

that accuracy of these arrivals was sufficient to give a fair idea of some of the underlying structure. These data, figure 109, indicate a surficial effusive layer about 500 feet thick in which the P-wave speed is 6,600 feet/second. Beneath this is another layer extending to a depth of about 4,000 feet in which the P-wave speed is 9,900 feet/second.

It may be possible that the rock extending to ca 4,000 feet may be of the same material; namely, alternate flows of lava interbedded with scoria and thin layers of sediment, and that the interface representing the break between the two wave speeds may be the water table. The two wells at the headquarters area 8 miles south of the explosions are in this material throughout their depth of nearly 700 feet.

6. *Air waves.*—Air waves from the 19 October blast are plotted in figure 110. The central plot is probably a sound wave originating directly at the blast. At 2 miles it contains the most energy. At 0.5 mile, an earlier wave which undoubtedly left the blast as a higher speed shock wave contains the most energy. The earlier wave is also a sound wave but it did not originate as such at the blast. It becomes relatively feeble at 2 miles. A third feeble wave with a slower apparent velocity is also recognized. It may be an echo from an upper stratum of air.

J.—METEOROLOGICAL DATA

Meteorological data were taken only during Test 1 and they have been fully discussed in Part IIA, par. 5j. It was anticipated that this explosion would have been heard and felt at much greater distances than it was. Some observers believe that the air blast and ground shock were less in this locality than they might have been in other parts of the United States. However, limited tests made by the Board along the Eastern Seaboard, after completion of the 1945 Arco tests, did not substantiate this belief.

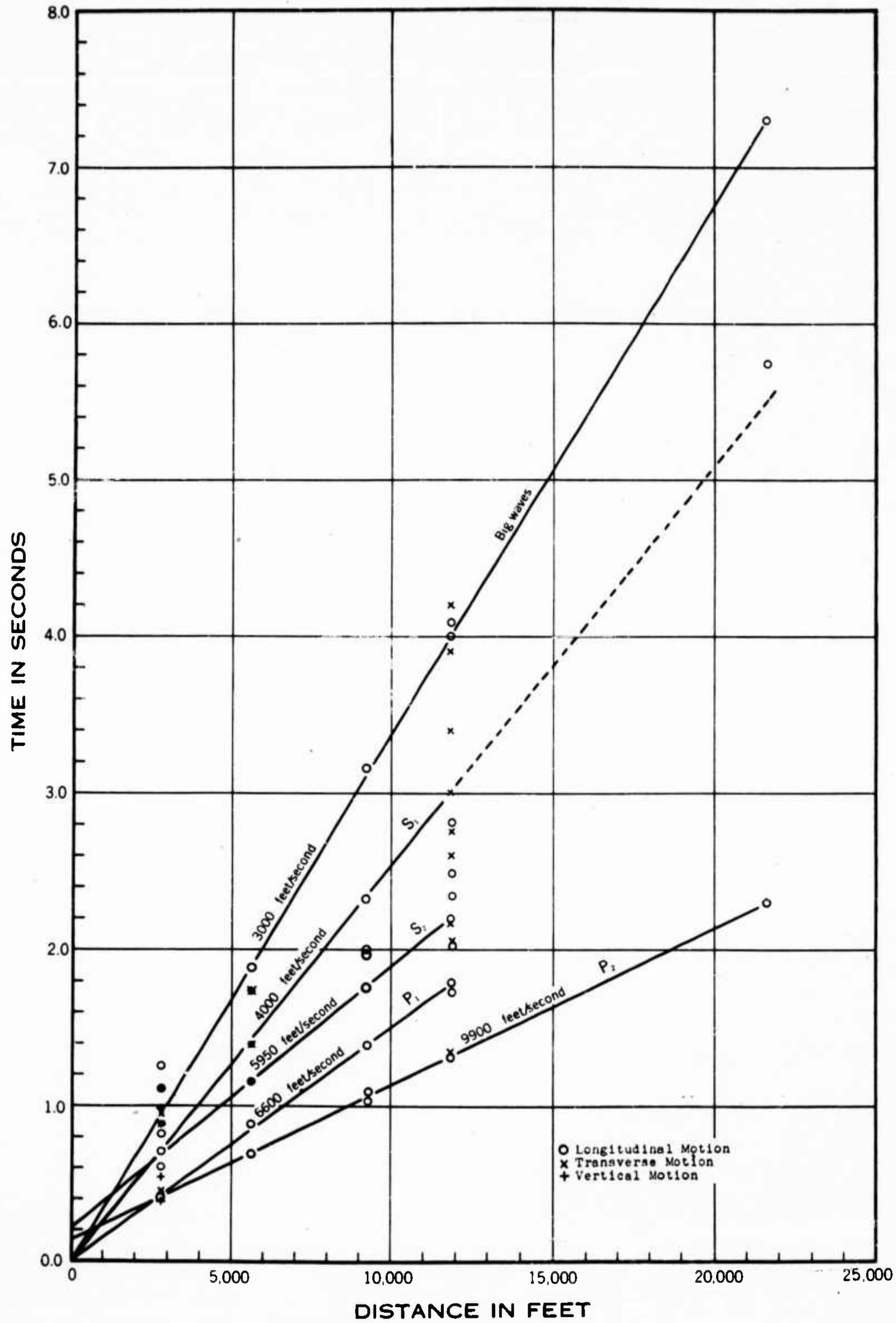


FIGURE 109. Travel times, Test 3.

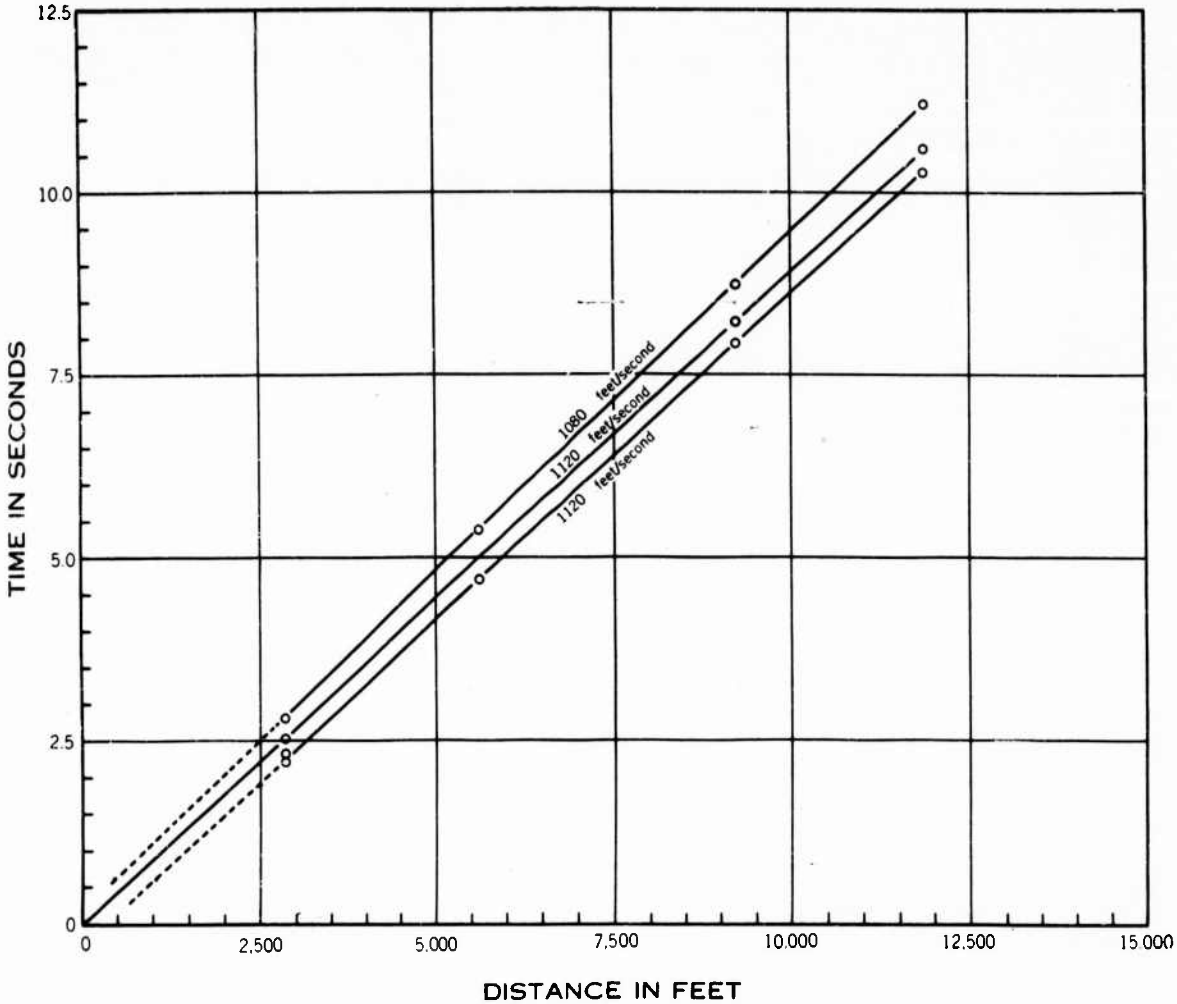


FIGURE 110. Air wave travel times, Test 3.

PART IV. CONCLUSIONS

A. The prescribed Army and Navy intermagazine safety distances for the storage of 250,000 net pounds of high explosives in igloo-type earth-covered magazines may be reduced from 400 feet Army (and 500 feet Navy) to 185 feet without undue risk of propagation of explosions from magazine to magazine.

B. The use of the barricaded distances prescribed for inhabited buildings in the ATD is not sufficient to prevent serious injury to personnel within the buildings from explosions in arch-type, concrete, earth-covered magazines.

C. The temporary storage of 250,000 net pounds of high explosives in an earth-barricaded open storage site located halfway between existing Army igloo-type earth-covered magazines is reasonably safe and permissible with respect to the nonpropagation of explosions from igloo to earth-barricaded open sites and vice versa.

D. The unbarricaded distance (800 feet) for 250,000 net pounds of high explosives stored in igloo-type earth-covered magazines affords reasonable protection against the propagation of explosions among open field stacks of mass detonating types of ammunition each containing 250,000 net pounds of high explosives.

E. The doors in the Navy igloo-type earth-covered magazines should be strengthened to provide better protection against explosions which may occur in adjacent magazines.

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